METALS & ALLOYS

Registered in the U. S. Patent Office

The Magazine of Metallurgical Engineering

INCLUDING METALLURGICAL ABSTRACTS

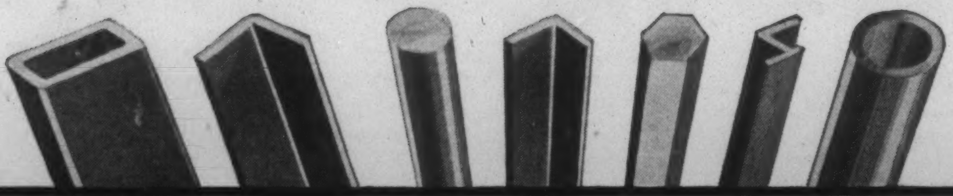
VOLUME 2

NOVEMBER
1931

NUMBER 5

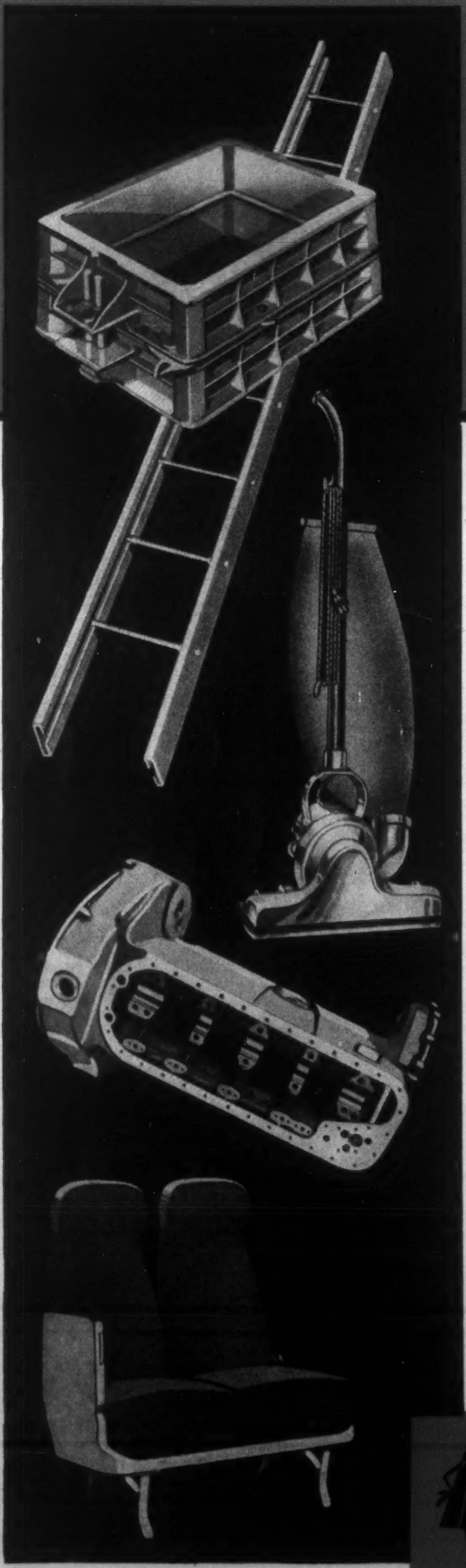
$3.00 a Year

$1.00 a Copy



Industry's Lightest Metal

IN WIDE VARIETY OF SHAPES • ¼ THE WEIGHT OF STEEL • MACHINES EASILY • DURABLE • *Good Engineering Properties*



Take useless dead weight out of your products

DOWMETAL lifts the costly burden of dead weight from industry's shoulders. And now, new low prices make it economically applicable to a wide variety of industrial uses.

Imagine a metal ⅓ lighter than other light alloys—less than ¼ the weight of steel—easy to machine—with good strength and durability!

Who knows but that this remarkable metal can add new sales appeal to your product, give you valuable competitive advantages through lighter weight, greater portability, easier handling, lower operating and maintenance costs?

Dowmetal ingots are now available in carload lots at 30c a pound and in l. c. l. lots at 32c.

Write for further information and prices on forms adapted to your product; also for your copy of the new Dowmetal Data Book.

Dowmetal Division
THE DOW CHEMICAL COMPANY
Midland, Michigan

Lbs.

DOWMETAL
MAGNESIUM ALLOYS

NOW YOU CAN MAKE IT OF DOWMETAL

METALS & ALLOYS

The Magazine of Metallurgical Engineering

H. W. GILLETT, Editorial Director
Battelle Memorial Institute,
Columbus, Ohio

RICHARD RIMBACH, Editor

EDITORIAL OFFICE:
3619 Forbes St., Pittsburgh, Pa.

All Editorial correspondence should be sent to the above address

◆

Editorial Advisory Board

H. A. ANDERSON
Western Electric Company
W. H. BASSETT
American Brass Company
A. L. BOEGEHOLD
General Motors Corporation
P. H. BRACE
Westinghouse Electric & Mfg. Co.
R. A. BULL
Electric Steel Founders' Research Group
O. W. ELLIS
Ontario Research Foundation
JUNIUS D. EDWARDS
Aluminum Company of America
H. J. FRENCH
International Nickel Company, Inc.
S. L. HOYT
A. O. Smith Corporation
J. B. JOHNSON
Wright Field, Air Corps, War Department
JOHN JOHNSTON
United States Steel Corporation
JAMES T. MACKENZIE
American Cast Iron Pipe Company
JOHN A. MATHEWS
Crucible Steel Company of America
C. A. McCUNE
Welding Engineering & Research Corporation
W. B. PRICE
Scovill Manufacturing Company
H. A. SCHWARTZ
National Malleable & Steel Castings Company
F. N. SPELLER
National Tube Company
L. W. SPRING
Crane Co.
JEROME STRAUSS
Vanadium Corporation of America

◆

WM. P. WINSOR, Advertising Manager

ADVERTISING OFFICES:
MAIN OFFICE, 3619 Forbes St., Pittsburgh.
CHICAGO, 1050 Straus Bldg.
CLEVELAND, 953 Leader Bldg.
NEW YORK, 419 Fourth Ave.
SAN FRANCISCO, 381 Bush St.

◆

PUBLISHED MONTHLY BY THE CHEMICAL CATALOG COMPANY, INC.

Francis M. Turner, Pres.
H. Burton Lowe, Vice-Pres.
Howard Myers, Vice-Pres.
R. W. Reinhold, Secy.-Treas.

◆

Annual Subscription: U. S., Possessions, Mexico and Cuba, $3.00, All Other Countries, $4.00.

All communications relating to subscriptions or back issues should be addressed to METALS & ALLOYS, 419 Fourth Avenue, New York.

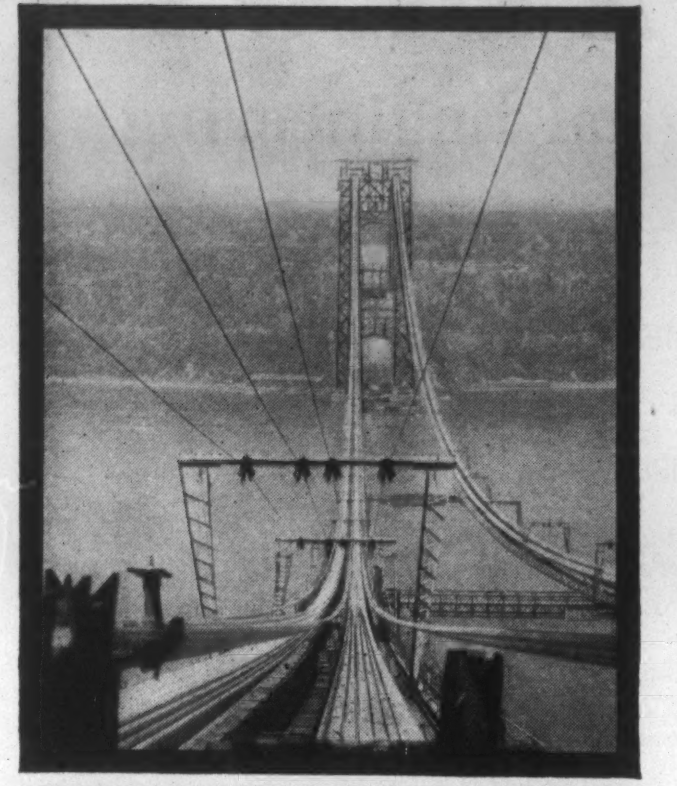
Copyright, 1931, by The Chemical Catalog Company, Inc. All rights reserved.

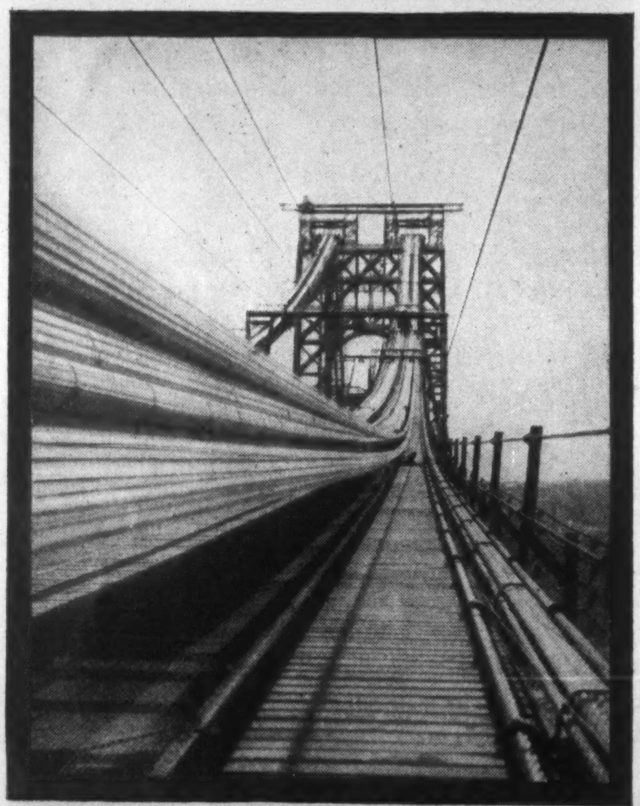
CONTENTS—NOVEMBER, 1931

Oxy-Acetylene Welding of Alloy Steels and Irons 253
J. H. Critchett
Soft Solders and Their Application 257
G. O. Hiers
Automatic Arc Welding of Steel Sheets 262
A. M. Candy
The Adherence of Zinc Coatings 266
William H. Finkeldey
Atomic Hydrogen Arc Welding 272
J. T. Catlett
Silver Solders and their Use 278
R. H. Leach
Copper Brazing in Controlled Atmosphere Furnaces 284
H. M. Webber
The Midvale Research Laboratory 288
Richard Rimbach
Energizing Action of Various Chemicals in the Carburization of Steel with Solid Carburizing Agents 290
R. A. Ragatz and O. L. Kowalke
The Lead-Zinc Eutectic 297
J. M. Hodge and R. H. Heyer
Preferred Orientation Produced by Cold Rolling in the Surface of Sheets of Aluminum, Nickel, Copper and Silver . . . 302
Cleveland B. Hollabaugh and Wheeler P. Davey
Endurance of Welded and Unwelded Cast Wrought Materials 313
W. B. Bartels (A Critical Abstract by H. W. Gillett)

METALLURGICAL ABSTRACTS

General........ 241
Properties of Metals........ 241
Properties of Non-Ferrous Alloys........ 243
Properties of Ferrous Alloys........ 243
Corrosion, Erosion, Oxidation, Passivity & Protection of Metals & Alloys. 245
Structure of Metals & Alloys........ 249
Physical, Mechanical & Magnetic Testing........ 255
Electro-Chemistry........ 257
Metallic Coatings Other than Electroplating........ 260
Industrial Uses and Applications........ 260
Heat Treatment........ 263
Joining of Metals & Alloys........ 265
Working of Metals & Alloys........ 268
Defects........ 273
Chemical Analysis........ 274
Historical & Biographical........ 274
Economic........ 275
Plants & Laboratories........ 276
Machinery & Supplies........ 276
Bibliographies........ 276
Miscellaneous........ 277
Foundry Practice & Appliances........ 278
Furnaces & Fuels........ 280
Refractories & Furnace Materials........ 281
Gases in Metals........ 281
Inspection........ 281
Effects of Elements on Metals & Alloys........ 282
Instruments and Controllers........ 282
Effect of Temperature on Metals & Alloys........ 283
Leaching........ 285
Reduction Metallurgy........ 285
Non-Metallic Coatings for Metals & Alloys........ 287





Horse Head

Uniform Quality Zinc

on the

George Washington Bridge

It was Horse Head Zinc galvanizing on the first great suspension cables—Brooklyn Bridge; it is Horse Head Zinc galvanizing on the newest and greatest bridge cables—The George Washington Bridge over the Hudson.

Horse Head Zinc's uniform quality has stood staunchly behind the development of these huge projects.

Horse Head Zinc was used on these bridges, among others:

- Brooklyn Bridge
- Delaware River Bridge
- Bear Mountain Bridge
- Mt. Hope Bridge
- Ambassador Bridge
- Mid-Hudson Bridge
- George Washington Bridge

Specifications for the George Washington Bridge *as furnished by* *The Port of New York Authority.*

Length of Bridge	4,760 ft.
Span	3,500 ft.
Feet above water	250 ft.
Number of Cables	4
Diameter of each	36 in.
Number of wires in each	26,474

Weight of Zinc for Galvanizing 1,700,000 lbs.

The New Jersey Zinc Company

160 Front Street New York City

EDITORIAL COMMENT

THE JOINING OF METALS AND ALLOYS

If two metallic molecules get close enough to each other, one or both being in the liquid state, they will, in general, cohere or adhere tenaciously when the liquid freezes. The crystals of a pure metal, forming as the melt freezes, build up in regular orientation due to strong directive forces of cohesion. If two or more metals are concerned, we get alloying through adhesive forces. The cases of "incompatibility" or immiscibility are relatively rare, and even in cases like copper and lead, immiscible in certain temperature ranges in the liquid state, the frozen metals usually show a considerable degree of adhesion.

Even in the solid state, provided the molecules can be brought into true metallic contact, the forces of adhesion and cohesion are great. Platinum can be hammer-welded far below its melting point, and tin-coated lead foil is made by simply rolling the two sheets together; even room temperature, for these low-melting metals, presumably gives the atoms a sufficient range of amplitude, so they can rather readily get into each other's field of force, and adhere in a manner somewhat analogous to the adhesion among the atoms of a chemical molecule. The metal crystal has unsatisfied forces at its surfaces, like valence "arms" reaching out to grasp the arms held out by other atoms. If no other metal atom comes close enough to be grasped, the "arm" is anxious to grasp almost any kind of atom that comes along. The greater the surface, the greater the unsatisfied forces radiating from it. Hence the difference between the properties of massive metal crystals and of those of colloidal size in which the surface is so great that the surface forces are overwhelmingly important.

This great chemical activity of a metallic surface leads to the adsorption of gas films, or the formation of oxide films. If the presence of such films could be avoided, and if pieces of metal could be prepared flat within the distance over which the force fields or valence arms are reaching out, we could then pile disks of most metals and alloys up like a stack of coins, and we could not unstack them; we should have to cut them apart, for the pile would be welded together into a solid cylinder.

If, by a sliding pressure, true metallic surfaces are produced, free from surface films, and are brought into close contact, the metals may "seize,"as in a valve seat or in a bearing running without lubricant.

In ordinary metal-to-metal wear, there are probably two kinds of gripping of the co-acting metallic faces. One is a mechanical interlocking of tiny projections on both faces; the other, an adhesion or cohesion, i. e., localized seizure.

To secure a joining of metals, the requirements are that truly clean metallic surfaces shall come into true contact. All the processes of welding, soldering, brazing, amalgamation, electroplating, tinning, hot galvanizing, sherardizing, metal spray, the manufacture of "duplex" metals, and so on, merely require that the two demands of cleanliness and contact be met. If they are, Nature will take its course, and join the metals.

In order to produce clean metal surfaces, heating is usually necessary to expel the adsorbed gas film, and fluxing to remove the oxide film which results from the metals we use being immersed in the sea of air in which we live. The dentist can tamp down a filling of gold foil, and make it cohere into a pretty dense solid. The welding of platinum has already been referred to. These noble metals probably do not form an oxide film, so all we have to contend with is the layer of adsorbed gas.

Metals like chromium and aluminum which tend to form very thin, tough adherent oxide films, and to repair them instantly when damaged, are apparently almost inoxidizable, but actually owe their surface resistivity to their great ease of oxidation. If an aluminum surface is amalgamated, the oxide film is not coherent and protective, and oxidation goes on in moist air till the aluminum is all converted to oxide. Aluminum and chromium and their alloys are hard to weld or solder because it is so hard to get a truly clean metal surface.

Aluminum solders are legion, and in ninety-nine cases out of one hundred, worthless, partly because of their attack by moisture, and partly because they are not applied under conditions allowing of good fluxing of the surface. In welding alloys of aluminum or of chromium, a good oxide-solvent flux is more than half the battle.

The difficulties met in the melting of dirty aluminum borings and in the condensation of zinc with avoidance of the formation of blue powder, are examples of the effect of foreign materials clinging to the surfaces of liquid globules, and preventing their coalescence. These difficulties are analogous to those met in welding.

If the metal to be applied in the molten state to the surface of another solid metal were readily able to dissolve the oxide film on the surface of the other, it would need no special flux, but in welding or soldering, we must generally use some flux which will dissolve the oxide film, and be itself readily displaced when the weld metal or solder meets it.

We make it easier for the flux to operate if we first remove heavy films as by pickling, filing or scraping, so that we have only to flux away what film forms in the short time before the flux can be applied.

Fluxes need not be liquid. A hydrogen atmosphere at a suitable temperature will reduce most oxides, and thus drive off the oxygen as water, leaving clean reduced metal on the surface, with only an adsorbed hydrogen layer to be removed.

It is usually more difficult to bring two solid metals into molecular contact, and at the same time drive out the oxide film, than it is to get contact between a solid and a liquid metal. Hammer welding in air should leave more of a crumpled oxide film in the weld than fusion welding, as in the latter the oxide film should tend to float up. But hammer welding in hydrogen ought to make a good clean joint.

An apparent oddity in soldering is the fact that the thinner the solder film in the joint, the stronger the joint. In other words, the forces of adhesion between the face of the metal to be soldered and the solder are stronger than the cohesive forces in the solder itself. This situation is also met in gluing. An ingenious utilization of this fact depends on the remarkable fluidity of fully deoxidized copper. In hydrogen brazing by copper, the copper will crawl by capillarity into unbelievably narrow crevices, so that close-fitting joints can be copper brazed, and the joints are strong. Much of the success of tungsten-carbide tools depends on the copper brazing of the tool nose to a tougher body. While hydrogen as a flux in other kinds of welding and soldering as yet finds relatively little use, it should tend to give a cleaner joint than most types of welding in air.

Welding is growing to be a science in itself, and it would take a good deal of space even to enumerate all the various methods, from thermit to electro-percussive.

Of special value are the mechanical welding methods, notably the electrical resistance methods, whereby carefully fitted surfaces are brought together under definite, measurable and reproducible pressure, and a definite amount of heat can be supplied. Under such procedure, we can be reasonably certain that of two consecutive joints, the untested one has properties similar to that of the one we chose for test.

Hand welding is an art in which the human element enters to so great an extent that, despite the acknowledged strides in the art, it seems to be greatly handicapped in comparison to methods that can be mechanically controlled. We always shudder a bit when life depends on the perfection of a hand-welded joint in any structure. Every step toward the mechanization of welding is surely a step in advance.

All the methods of joining metals, some of which are described in articles in this issue, have special techniques and special uses, but a thoroughly sound joint made by any of them must have been made by observing the requirements as to cleanliness and contact. They may therefore all be classed together as utilizing the forces of adhesion or cohesion—those forces which we use so much, but which we understand so little.—

H. W. Gillett

The Joining of Alloy Steel

That the trend of the metal using industry is directed toward alloy steels is realized in the vast increased tonnage of steel containing various alloys for industrial products of every nature. Many of these articles were formerly considered as definitely belonging only to the very common grades of plain carbon steels, due to both cost of the metal and methods of joining them

Among the many reasons found for the change to alloys are improved physical properties such as tensile strength combined with ductility, and longer life due to its corrosion resisting properties, the need for these improved properties being due to the ever increasing demands on metals in various industrial fields. In the majority of cases a slight change in design of the vessel with no additional weight of material practically eliminates the earlier question of cost of the base metals.

With the increase in use of alloy steels has come the increased need for welding these metals as an economical means of fabricating. There is probably no single welding problem more outstanding than that of welding alloy steels and the answer is by no means complicated if the problem is properly approached. The welding process has been fully established in the field of the plain carbon steels, but the same standards do not apply to alloy steels either in regard to welding materials or procedure, and it becomes necessary to learn how to weld alloy steels. This means new methods of welding procedure, the development of new welding materials (filler metals), establishment of heat treatments, etc.

The metallurgical engineer is just as essential in the development of filler metals as he was in the development of the steel itself, in fact somewhat more so as there is a wide gap between the method of producing a weld and that of an ingot, a rolled plate or a sheet.

Therefore, to produce what is termed a perfect weld, i. e., one whose properties both physically and chemically are the same as the base metal, proper welding procedure must also be established by the welding engineer, and the metallurgist and engineer must work hand in hand.

So far there has been a considerable amount of success in welding alloys but we are in about the same position in this field as existed in ordinary steels five years ago, and while it has been common practice for some time to secure perfect welds in commercial steels, the early trials and tribulations of welding ordinary steels is a lesson long to be remembered by those who have devoted time to the problem. This welding perfection came about only by the application of scientific methods resulting in what has now become simplified standards, and for welding to obtain the same degree of security in alloy steels, the same scientific fundamentals will have to be applied.

Fortunately to-day, with the advanced knowledge of welding and modern non-destructive method of testing the finished welds, the success of welded alloy steels is a certainty.—C. A. McCune

(Continued on page 271)

Oxy-Acetylene WELDING of Alloy Steels and Irons

BY J. H. CRITCHETT*

MODERN metallurgical practices within the past few years have supplied many of the demands of industry through the development of various types of alloy steels, many of which have been designed to solve some specific problem such as high strength; or resistance to corrosion, high temperature and pressure, impact, fatigue or abrasion. As these new metals were introduced, the question arose as to the best method of joining them. Since oxy-acetylene welding had proven so successful in its application to the common metals such as ordinary steel and cast iron, aluminum, brass and bronze, engineers naturally turned to this process as a means of solving this problem.

Exhaustive studies have shown that oxy-acetylene welding is especially well adapted to joining practically all of the alloy steels. Each alloy presents an individual welding problem due to the different metallurgical characteristics introduced by the alloying element. However, the flexibility of the process is such that by slightly changing the welding technique nearly all of the present-day metals can be successfully joined.

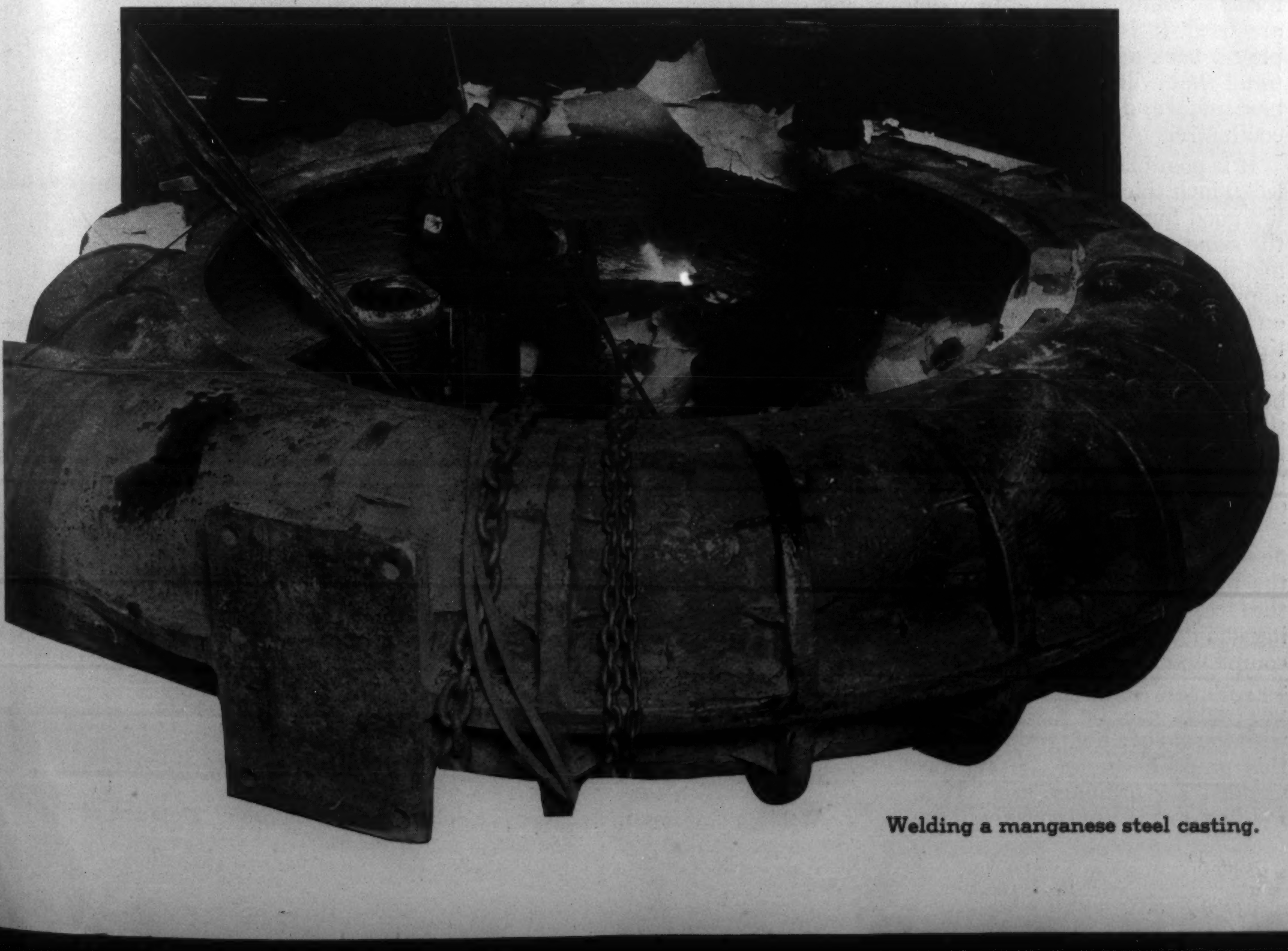
Probably the best known and most widely used of the new metals are the chromium and chrome-nickel alloys, of which there are many sold under various trade names. Consideration of the proper welding procedure for these various alloys is simplified by dividing them into several groups, according to their alloy content.

CHROMIUM ALLOYS

The low-chromium steels present no welding difficulties as long as it is kept in mind that subsequent heat treatment is necessary to obtain the highest physical properties. Therefore, this discussion will be limited to those alloys having a high chromium content. In all cases there are certain general precautions that should be followed and may be mentioned as pertaining to all of the chromium and chrome-nickel steels.

In the welding of the chromium and chrome-nickel alloys the proper adjustment of the blowpipe flame is of the utmost importance. If an oxidizing flame is used an excessive quantity of infusible oxides will be formed which leads to porosity. An excess acetylene flame increases the carbon content of the weld and adjacent metal and reduces the resistance of the alloy to corrosion. Hence the importance of a neutral flame is evident. The blowpipe flame should be adjusted by first supplying too much acetylene and then cutting back the flow until the acetylene feather just disappears. Any very slight excess of acetylene present in the flame adjusted according to this procedure will not materially affect the corrosion resistance of the weld metal. The flame should be no larger than is necessary in order to insure proper fusion, and to avoid overheating.

While the use of a suitable flux may not be absolutely necessary, extensive tests have proved that better results are obtained with the oxy-acetylene process if a



Welding a manganese steel casting.

---

* Vice-President, Union Carbide and Carbon Research Laboratories, Inc.

Welded Chrome-nickel steel piping.

proper flux is employed. Such a flux should be capable of dissolving iron and chromium oxides. At the welding temperature of these alloys it should produce a fusible slag that is neither too viscous nor too fluid, and that will assist in quickly floating impurities to the top of the weld. Since ordinary welding fluxes will not fulfil all these requirements, a special flux such as Cromaloy flux, which is especially adapted for this type of work, will give the most satisfactory results. In every case the surfaces to be welded should be clean and free from mill scale and oxides.

The majority of the chromium alloys can be welded either in thin gage sheets, plates or castings. For sheet 16 gage and under, flange welds are usually employed although butt joints are frequently encountered. In flange welding the edges of the sheet to be joined are bent up or flanged for a depth of about $^1/_{16}$ inch. The flanged edges are painted top and bottom with a water-mixed paste of flux and then melted down to form the joint. When butt welds are used, it is necessary to employ a back-up strip of some material that will not alloy with the base metal and that has high heat conductivity.

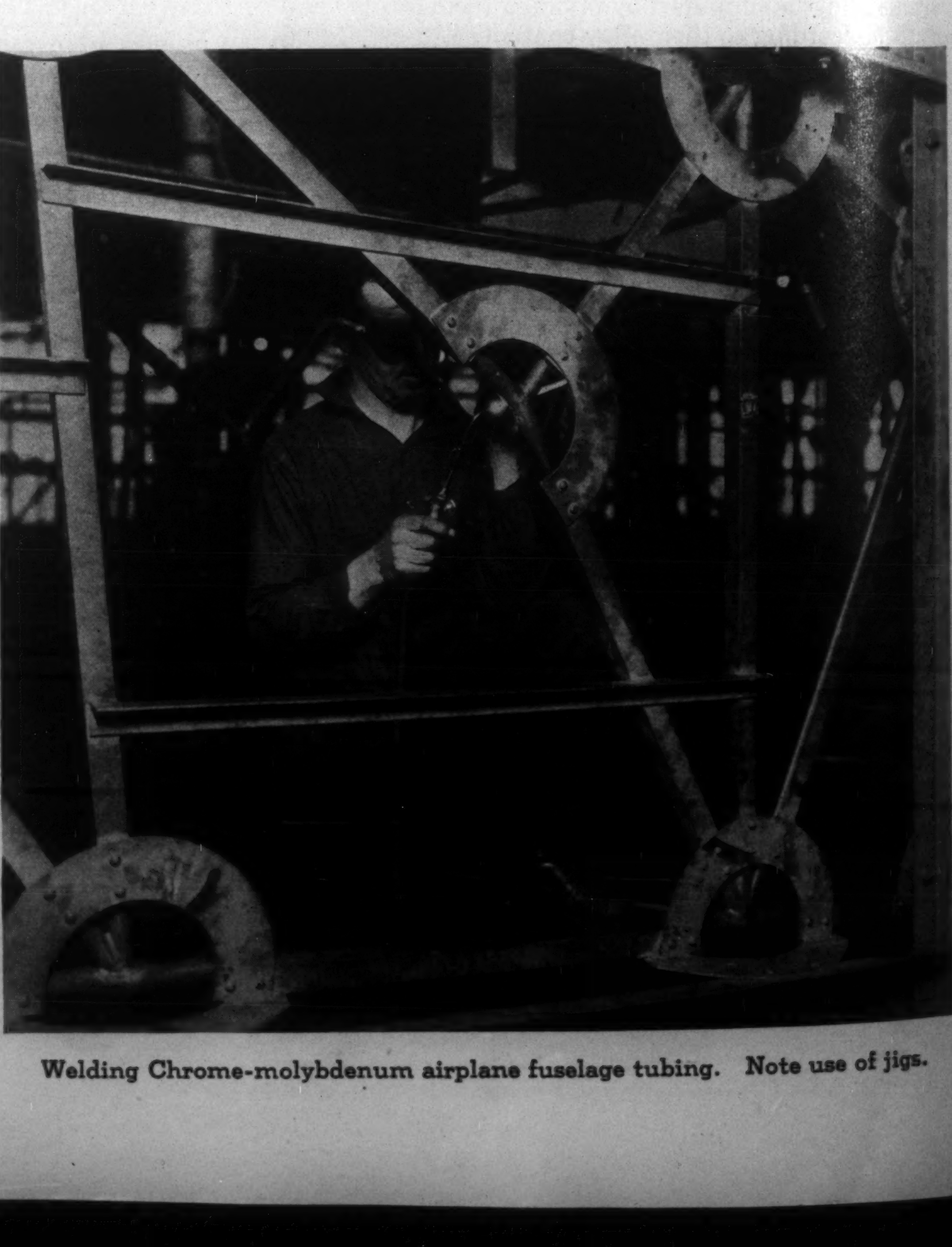
It is possible to weld metal $^1/_{16}$ to $^1/_8$ inch thick without beveling if a good flux and welding rod of the same composition as the base metal are used. The flux must be applied to the line of the weld on both sides of the sheet in order to prevent oxidation on the under side and to insure good fusion beneath the protecting film of slag that is produced. It is practically impossible to obtain complete penetration to the bottom of the seam unless the proper flux is employed. In welding thicknesses over $^1/_8$ inch, the edges of the plate should be beveled and the faces coated with flux. Welding should be carried through to completion as rapidly as possible and on one side only. Double-vee welds can be accomplished with the aid of a high preheat, but this practice cannot be recommended for ordinary use. If a welding rod is used, it should be allowed to flow onto the metal, because puddling will cause weak, porous welds.

In welding castings the entire piece should be preheated to a good red heat, and allowed to cool slowly. Subsequent heat treatment may be necessary to furnish the required hardness. Welding rod of the same composition should be used, and if the carbon content of the metal is high, an excess acetylene flame may be employed to facilitate welding. No more acetylene should be used than is necessary, and in any case a feather of acetylene the same length as the inner cone should be considered a maximum.

The preceding welding procedures may be applied to any of the chromium or chrome-nickel alloys, and if these are carefully followed and the proper method of heat treatment adhered to, the maximum strength and ductility will be obtained. The proper heat treatment will be discussed under the individual groups.

4-6% Chromium Alloys. These alloys, which are relatively low in chromium, exhibit welding characteristics somewhat similar to those of steel. However, a heavier coating of infusible slag is formed during welding, so that the use of a suitable flux is necessary. If the carbon content of this material is high, it is necessary to heat treat the metal after welding and to allow it to cool very slowly.

12-16% Chromium Alloys. This group of alloys may be further divided into those containing 0.20% carbon or over and those containing less than 0.12% carbon. The high carbon variety is very susceptible to heat treatment and to surface finish for its corrosion resistant properties. The metal air hardens, so that welds and adjacent base metal will be hard and brittle.

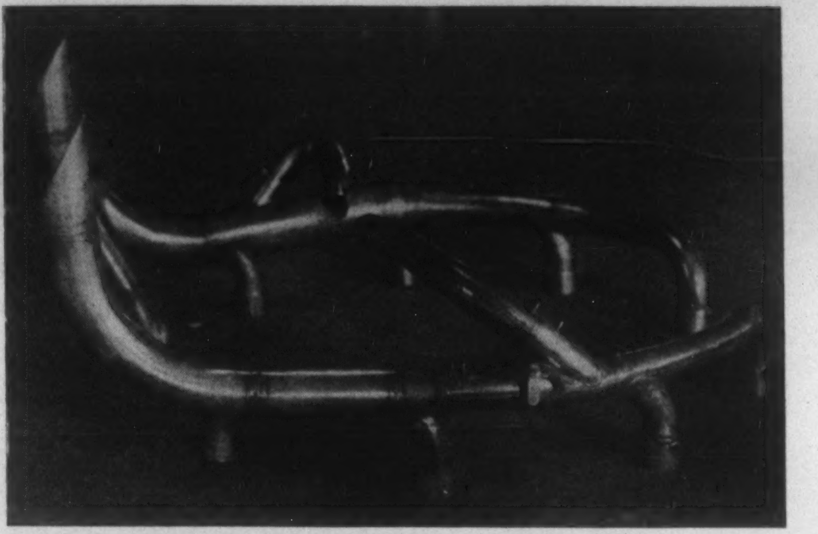


Welding Chrome-molybdenum airplane fuselage tubing. Note use of jigs.

Annealing and slow cooling will remedy the condition somewhat, but quenching and drawing followed by careful surface refinishing are necessary to develop its maximum stainless properties.

The low carbon alloy does not require heat-treatment to develop its corrosion resistant qualities, but its air hardening characteristics when heated above 790–800° C. (1455–1470° F.) demand subsequent heat treatment in order to remedy the hardness and brittleness of the weld and adjacent metal. Excellent results are obtained by heating to about 750° C. (1380° F.) for $^1/_2$ hr. and cooling either in the furnace or in still air. Although furnace annealing is recommended, blowpipe annealing will aid considerably where it is not possible to use furnaces. Welds should always be heat treated to restore toughness and ductility to the metal affected by the welding heat.

16-20% Chromium Alloys. The technique recommended for the welding of the 12–16% chromium alloys applies also to these. However, the high silicon content which is often found in the higher chromium-grade facilitates welding. The metals in this group do not air harden as readily as the lower chromium alloys, but they are liable to grain growth at welding temperatures. Heat treatment similar to that advocated for the 12–16% chromium grade will impart toughness and ductility to the welds. Care should be taken to prevent heating above 780° C. (1435° F.) however.



Welded Chrome-nickel steel exhaust manifold for aircraft.

20-30% Chromium Alloys. Because of the high chromium content of these alloys, an infusible slag is formed which occasionally presents some difficulty in welding, particularly on heavy sections. The use of flux in such instances tends to remedy this situation to a great extent. This material does not self-harden, but it is subject to grain growth at welding temperatures. Care should be taken to prevent any sudden changes in temperature during welding. The metal is ductile at a black heat (475° C.–885° F.); but if it is held at this temperature or allowed to cool through it slowly, it will be extremely brittle when cooled. However, this condition can be remedied by rapid cooling through this range or subsequent reheating to a red heat and cooling quickly through this range. In large sections it is best to preheat the entire piece to a good black heat and then carry welding through to completion in one operation. Welds and adjacent base metal will be strong but exceedingly brittle if not subsequently heat-treated.

Repairing a chrome-nickel steel gear.

CHROMIUM NICKEL ALLOYS

The general welding technique as discussed under the heading of chromium alloys applies equally as well to the chromium nickel alloys. Modifications in technique made necessary by special characteristics are discussed more completely under the individual groups.

17-25% Chromium-7-12% Nickel Alloys. These metals are austenitic in structure and are not subject to the brittleness encountered in welding the nickel-free chromium alloys. No subsequent heat treatment is necessary in order to obtain good strength and ductility in the welds and adjacent metal. When water quenching from high temperatures is possible, the cold working and corrosion resistant properties of these alloys are greatly improved. However, the distortion resulting from this practice limits this treatment to a few products and is only necessary where extremely corrosive conditions are to be encountered.

If the alloy contains more than 0.08% carbon it has been found that under severe corrosive conditions intercrystalline corrosion occurs in the base metal adjacent to the weld. This is probably caused in part by carbide precipitation at the grain boundaries. Subsequent heating to above 1000° C. (1830° F.) followed by air cooling or quenching will remedy this difficulty and should be used wherever welded high carbon alloys of this type are to be used to resist severe corrosion. Most manufacturers fabricate more than one grade of these alloys, those having the lower carbon content of less than 0.10% being preferable for welding.

In welding the 18–8 chromium-nickel alloys it should be remembered that their coefficient of expansion is about 50% greater than that for mild steel and that their thermal conductivity is but 48% that of steel. Suitable preheating coupled with the proper use of jigs and chill plates will remedy the tendency to buckle.

7-25% Chromium-17-22% Nickel Alloys. These alloys, developed to meet certain specific requirements of various industries, vary so much in composition that it is impossible to formulate any general welding technique. Each alloy requires a different procedure so that in order to obtain the most satisfactory results the alloy manufacturer should be consulted as to the proper welding practice.

18% Chromium-8% Manganese Steel. This alloy is a comparative newcomer to the alloy steel field and has been used particularly where resistance to sulphur bearing gases is required for applications. It is welded similarly to the chromium-nickel alloys, but joining is accomplished more easily. A neutral or slightly reducing flame is important, as is the use of a good chromium flux. It is undoubtedly the most easily welded of the high chromium steels, strong ductile welds being readily obtained.

MANGANESE STEELS

1-2% Manganese Steel. This material may be readily welded by the ordinary technique employed for mild steel. The use of manganese-molybdenum welding rods will assure the best results. Subsequent heat treatment appears to have little effect upon strength and ductility.

12% Manganese Steel. Hadfield steel, one of the first of the alloy steels, is the usual name under which this metal is sold. A special rod of similar composition to the base metal should always be used. The pieces to be welded should be prepared and preheated according to the usual cast iron welding procedure, care being taken to support heavy sections against strain because of the weakness of red hot manganese steel. A slightly reducing flame facilitates obtaining sound welds, and a large flame should be used to maintain a large pool of molten metal. The rod should not be rubbed into the weld but should be kept in the pool and melted under the surface of the liquid metal. After a large pool is developed, it should be melted into the base metal.

ENGINEERING TYPES OF ALLOY STEEL

None of these alloys presents any difficulties in welding, the proper technique in every case being the same as for plain carbon steel. Since these steels are used mainly to obtain high strength with good ductility, resiliency and resistance to shock, heat treatment after welding will insure the most satisfactory results. Normalizing may be accomplished either by means of a furnace or the welding blowpipe, although the use of a furnace where possible will undoubtedly prove the more satisfactory. The welds should be allowed to cool to a black heat and then reheated through the critical range of 760° to 815° C. (1400° to 1500° F.) care being taken not to heat above this upper limit in order to prevent grain growth. The piece should be held at this heat for a few minutes and then allowed to cool at a rate equal to the cooling of an average section in still air. The proper cooling rate is necessary in order to insure the most satisfactory results. In some cases tempering may be necessary after normalizing.

HIGH SILICON IRON

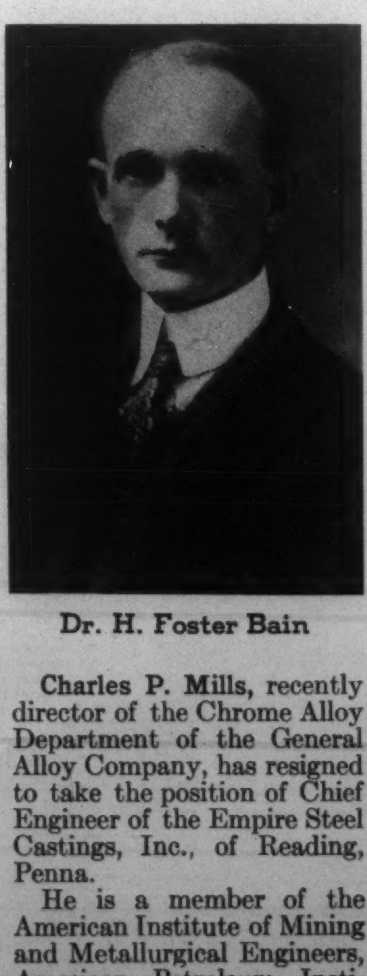
High silicon irons such as Duriron, which contains about 14% silicon, can be welded; and if the proper procedure is carefully followed, welds as strong and as corrosion resistant as the base metal will result. A rod of the same composition should be used; and the use of a flux composed of equal parts of borax and sodium bisulphate is recommended. A neutral flame should be employed and the rod kept in the molten pool underneath the heavy slag coating that is formed. Since molten Duriron is very fluid, welding must be carried through more rapidly than is usual with cast iron.

In repair work the metal around the fracture should be melted away until clean iron is reached. Holes should be backed up with a molding sand and then filled from the rod. A sand backing should be used when welding is done on a flat surface. The edges of the pieces should be melted down to form the weld at the base of the vee, and then the remainder built up from the filler rod.

CONCLUSION

Undoubtedly there are scores of alloys welded every day that have not been mentioned in this discussion, but it is felt that the preceding list covers with fair completeness the scope of the alloy steels and irons commonly encountered in general welding practice today. There are few exceptions to the list of alloys that can be satisfactorily welded by the oxy-acetylene process provided the composition of the metal is thoroughly understood, and the proper welding technique as set forth in this paper, and in the various booklets published by welding supply and alloy steel manufacturers is carefully followed.

◆ ◆ ◆



Dr. H. Foster Bain

Dr. H. Foster Bain, former Director of the U. S. Bureau of Mines, and more recently Secretary of the American Institute of Mining & Metallurgical Engineers, has resigned from the Secretaryship to take over work of the Copper & Brass Research Association.

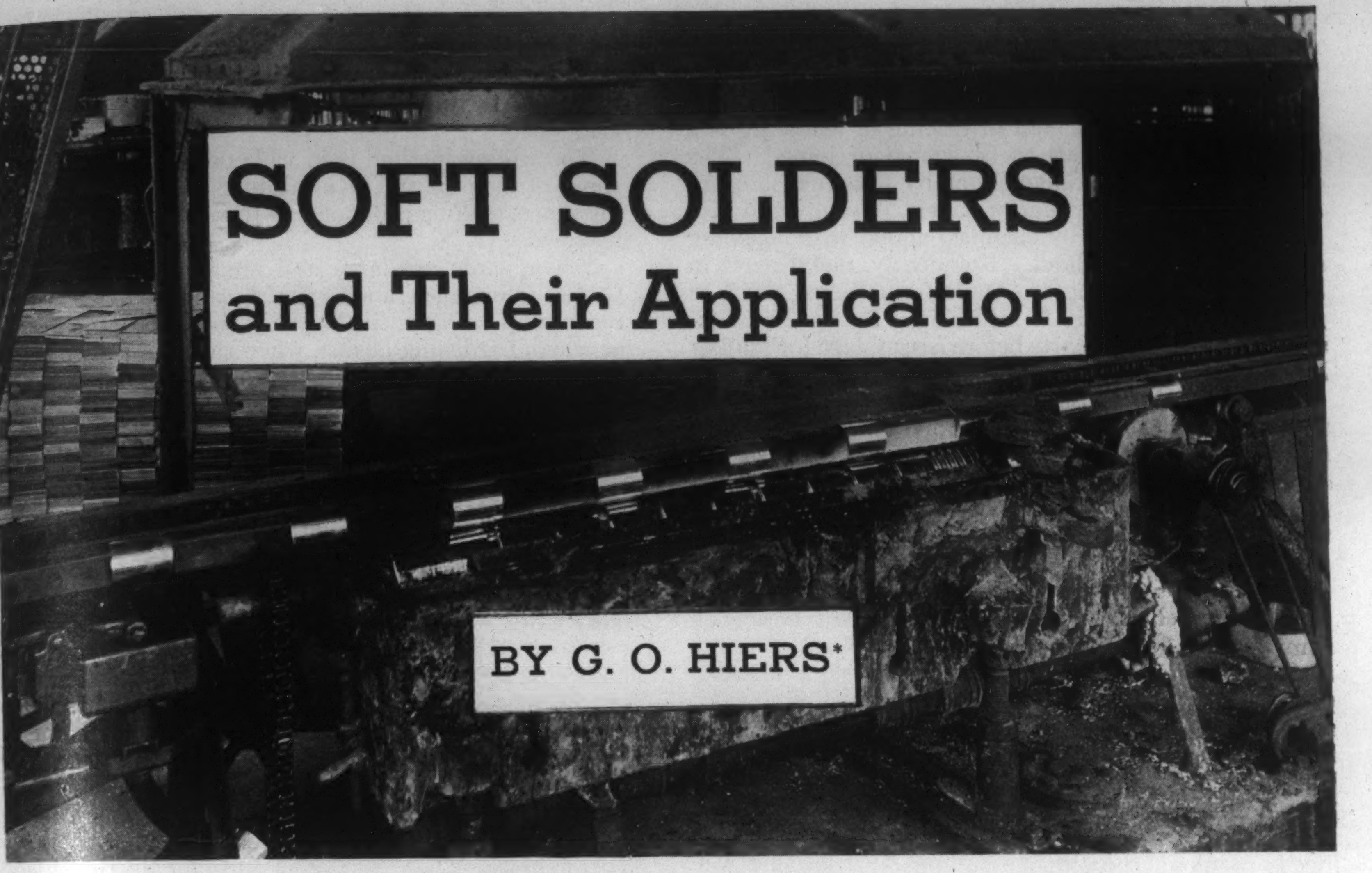
Charles P. Mills

Charles P. Mills, recently director of the Chrome Alloy Department of the General Alloy Company, has resigned to take the position of Chief Engineer of the Empire Steel Castings, Inc., of Reading, Penna.

He is a member of the American Institute of Mining and Metallurgical Engineers, American Petroleum Institute and the Engineers' Society of Western Pennsylvania.

SOFT SOLDERS and Their Application

BY G. O. HIERS*



Machine for Soldering Tin Cans.

COMPOSITION

SOFT solders refer to lead-tin alloys used for solder metal. They are more fusible than the hard solders which contain practically no lead or tin. Hard solders include brazing solders and silver solders. Fusible alloys are more fusible than soft solders and in addition to lead and tin, they contain bismuth and sometimes cadmium or mercury. Occasionally they are used by methods resembling soft soldering.

In Fig. 1 the equilibrium diagram of the lead-tin alloys is given.[45] A more recently presented investigation gives data for the system somewhat at variance with this diagram[38] but the differences do not appear to be consequential in respect to the alloys referred to in this paper. In the ternary system, lead-tin-antimony, it is well to consider the equilibria of solder alloys containing a few percent of antimony. The "peritecto-eutectic point" has been placed at lead 40%, tin 57½% and antimony 2½% and the reaction temperature at 188° C. (370° F).[38] This is sufficiently close to Nightingale's[37] determination so that his generalizations, referred to later, on the permissible or desirable antimony content in solder may be accepted.

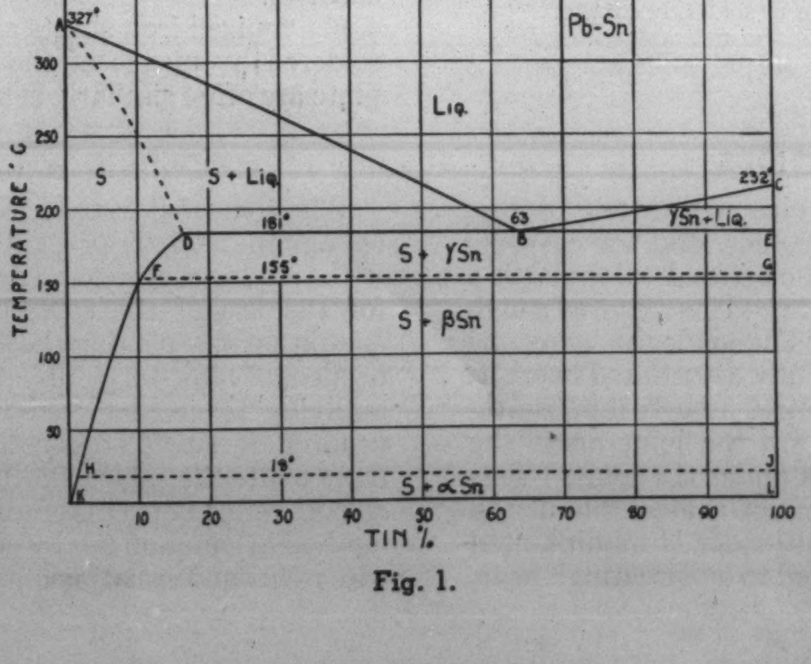


Fig. 1.

The American Standards Association has adopted the A. S. T. M. specifications for soft solder[36] which designate eleven compositions varying from 31–63% tin, 0.12 (or less) to 2.0% antimony, balance lead except for allowable impurities. The British Engineering Standards Association[24] lists eight solders somewhat similar and a ninth containing 95% tin, 5% lead. All of these solders are permitted to contain up to 0.3% antimony and others vary up to one in which 3% is allowable. When a solder is used for joining zinc or galvanized iron, antimony should be absent to avoid the formation of a relatively infusible zinc-antimony compound which objectionably reduces the fluidity of the solder.

For some purposes requiring slightly higher melting point solders, alloys are sometimes made to the following formulae:–

Pb	Sn	Sb	Ag	Tl.
95	5	..	..	..
..	94	6	..	..
98	..	..	2	.. [35]
98	..	..	..	2

NATURE OF A SOLDERED JOINT

When soldering there is frequently an alloying action between the solder and the metals united. Alloying is desirable but not absolutely essential. Silberstein[35] has demonstrated that a reaction between metallic aluminum and lead chloride, with the aid of heat, produces a deposit of metallic lead which functions as a solder. Lead and aluminum do not alloy with each other.

---

* Metallurgist, National Lead Co. Research Laboratories.

Nightingale[37] explains all by saying that a solder must be adhesive. He ascribes to the Americans the three rules for good soldering, namely: cleanliness, cleanliness and cleanliness.

Generally, the first step in tinning or soldering is a cleansing of the metals to be coated or joined. The operation may be mechanical as by scraping, filing or rubbing with sand or emery paper. Usually the preliminary cleansing is by chemical action with pickling solutions of acid or alkali. Frequently, metal parts to be joined by soldering are made from tinned sheet or wire in order to facilitate soldering. It is often desirable to pre-tin metal parts before assemblage for joining by soldering.

For practical purposes, it is generally necessary to use a flux when soft soldering. The chief functions of fluxes are to dissolve oxides and to prevent oxidation of the surfaces of metal to be joined. They should also be fluid at the temperature of the molten solder applied so that by gravity, capillarity or other forces the solder can displace the flux at the joint made. Mild fluxes such as tallow, stearin and rosin particularly prevent oxidation, whereas zinc chloride, with or without the addition of ammonium chloride, acts both as an oxidation preventative and a scavenger. Zinc chloride has a melting point of 262° C. (504° F.) and its eutectic mixture with ammonium chloride (71% by wt. $ZnCl_2$, 29% NH_4Cl) has a melting point of 179° C. (354° F.), fortunately just below the melting point of the eutectic alloy, 63% tin, 37% lead. The eutectic solder is sometimes used at a minimum temperature and where the zinc chloride type flux is required, the zinc-ammonium chloride eutectic mixture is desirable. The ordinary flux solution is zinc chloride made by dissolving zinc in muriatic (hydrochloric) acid. A popular paste flux contains about 75% petroleum jelly, 20% zinc chloride and 5% ammonium chloride with a small amount of water as an emulsifying agent.

METHODS OF APPLICATION

Tin, lead, zinc, copper, copper alloys, nickel, monel metal, iron, steel, stainless steel can all be readily joined with solder. The method of application of solder to the metals to be joined varies according to the character of the metals, their position, the size of the parts to be joined, the speed with which the operation must be completed, and the shape, tensile strength, and appearance required by the finished work. In every case, the surfaces to be soldered must be brought to the melting heat of the solder. The necessary heat is secured:

1. By repeatedly pouring the molten solder over the surfaces to be joined, in the wiping method.
2. By the use of the soldering iron or soldering copper.
3. By the use of blow-torch, or electric arc.
4. By solder-bath.
5. By sweating.

WIPING METHODS

For joining sections of lead pipe with brass, bronze, lead and copper fittings with solder, and for covering internal joints on lead-covered electrical cables with a lead sleeve, wiped joints are made. This requires a high degree of skill and practice. The solder in a plastic state is poured slowly, and carefully distributed over the top and sides of the joint. Being in a fairly fluid condition, some of the solder drops off the joint on to the cloth which the workman holds under the joint. This dropped solder is pressed up against the bottom of the joint and the whole mass of hot solder is manipulated till every part of the joint is raised to a "sweating" heat, which insures a perfectly tight contact all around. When this heat is attained, the pasty solder is shaped and rounded with the wiping pad, and all excess solder is wiped off as the joint slowly cools and the solder hardens.

The wiping method is in wide use because often the shape of the pipe and its location allow very little working space, making it impossible to use a tool or mechanical device.

When joints are large and are poured with ladles, perfect adherence and solidity can be obtained by repeated pouring until the joints cool to a temperature at which hardening begins, when the excess of solder is wiped off.

In wiping joints plumbers get some flux (tallow or lard oil) from the wiping cloth. In wiping cable joints stearin in stick form is used for fluxing.

Wiping solders in this country for making joints in pipes or for cable sheathing have been found by experience to be best in the range of 58-63% lead, the balance tin, although some users prefer the addition of up to 2% antimony. (In filling joints in automobile bodies, an alloy is used somewhat as a wiping solder and usually contains about 30% tin and 70% lead.) It may be noted from Fig. 1 that these alloys have a plastic range of about 60° C. (140° F.) between the liquidus and solidus which accounts for their choice since the alloy is maintained in a semi-liquid state for a convenient length of time while making the joint.

For wiping solders, the British Non-Ferrous Metals Research Association recommends a tin content of 30-31% and claims the addition of antimony to the extent of 6% of the tin content in no way impairs the working properties of the wiping solder so long as the tin content is not below 30-31%. They also state that it makes for small grain size and in general for good adhesion and soundness.

SOLDERING WITH A SOLDERING TOOL

A soldering tool is sometimes referred to as a soldering copper and sometimes as a soldering iron. It is usually copper, even when called an "iron."

The tool is used in soldering sheet metals together where the sheets are either lapped or locked together and present a flat surface over which the soldering tool may be drawn.

The tool is heated to a point hot enough to quickly melt the solder, which is drawn along the edges to be joined just fast enough to allow the heated iron and melted solder to heat the edges and secure a tight water proof seam. The soldering iron is also used to heat other surfaces to be soldered where it is practical to use neither a flame nor molten solder poured over the surfaces.

Galvanized iron sheets and copper sheets are usually soldered by means of the iron. Terne plate and tin plate are often similarly soldered.

SOLDERING WITH A BLOW TORCH

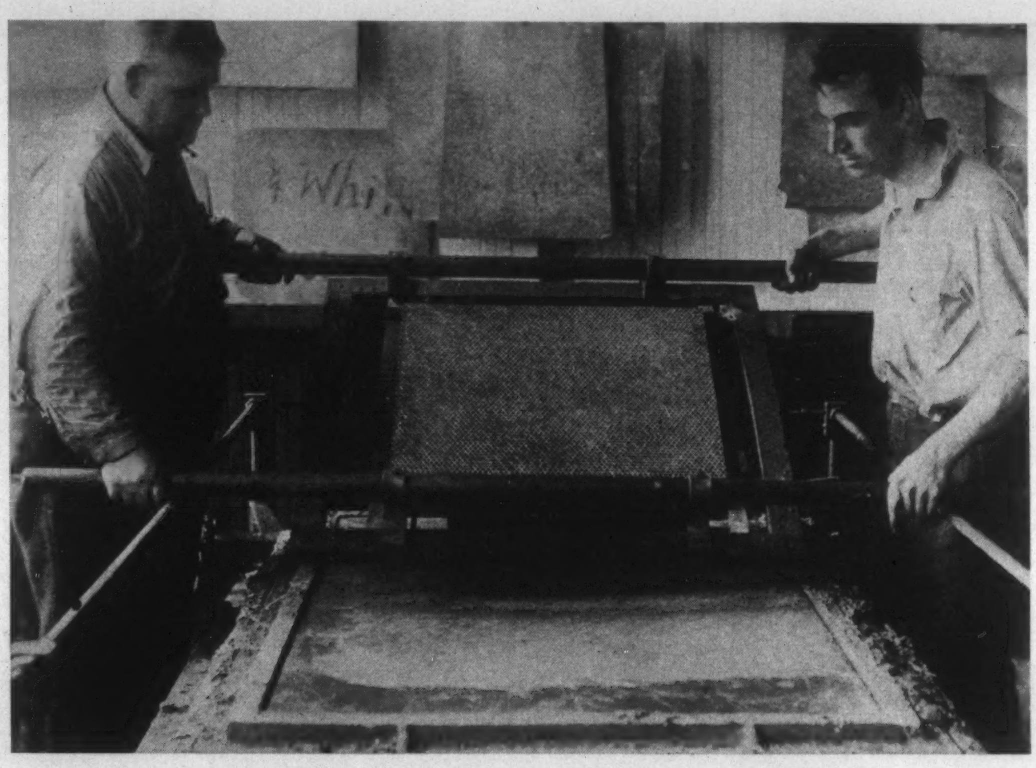
Where the metals to be joined or soldered are not large enough in diameter or rigid enough to permit of the use of the wiping method and are not flat surfaces in position for the use of the soldering copper, soldering is accomplished by playing the flames of a gasoline, kerosene or alcohol blow-torch directly on the surfaces and then applying the solder cold in bar or wire form of appropriately small cross-section. The heat of the surfaces melts the solder and before it hardens, it is wiped smooth and any excess of solder is removed. This is the method in common use by electrical workers in soldering wire joints and sweating on lugs.

THE SOLDER BATH

Where the parts to be soldered are too numerous or too small for the use of the methods previously described the soldering is done by means of a molten bath.

The soldering of automobile radiators is a good case in point. The radiator parts are assembled into frames, clamped tight and the ends are then dipped into a solder bath which is just deep enough to give the required depth to the joint. For this purpose the solder is purchased in slabs varying in size from 15 to 35 pounds. The popular compositions for the bath are $^{50}/_{50}$ and $^{40}/_{60}$ (respectively, tin and lead), although finer (tin richer) or poorer solders are used by some manufacturers.

The soldering of tin cans is another good example. The cans are carried through the bath by the means of a chain belt over a track which causes the cans to revolve. The track holds the cans at an angle of 45° so that the solder in the bath touches about $^{1}/_{8}$ inch of the bottom and side of the can, thus making the joint.



Dipping Automobile Radiator Cores in a Solder Bath.
(Courtesy Winchester Repeating Arms Company.)

SOLDERING BY SWEATING

The sweating process has been found best where a great number of metal objects are to be soldered with great rapidity and when they are of uniform size, allowing the use of automatic machinery. The soldering of machine-assembled, round tin cans is a good example. By machinery these cans can be assembled at the rate of 150 per minute. Many can manufacturers at a single plant turn out as many as 3,000,000 cans per day of ten hours.

As stated above, tin cans are sometimes soldered in a bath but sometimes the sweating process is used.

In that case, the cans are usually formed and the heads and bottoms crimped on by machinery. They are then carried by a travelling chain belt over tracks which cause the cans to revolve under a series of gas jets. The cans are thus heated. They are then passed under tubes through which wire solder is fed to the heated metal in the required amount for each can. The solder on coming in contact with the heated can immediately melts and flows or sweats into the crimped joint, making a securely soldered and air-tight seam.

The solder used in the above work varies from $^{37.5}/_{62.5}$ to $^{50}/_{50}$, popular compositions being $^{40}/_{60}$ and $^{45}/_{55}$. Each manufacturer has his own ideas on the subject.

OTHER METHODS

In soldering many specialties the foregoing methods have been modified or combined in groups, or special tools have been devised to fit the special conditions. However, none of these special shop practices embraces any new or different principle.

WORKING HEAT AND FLUXING

A pot of solder should never be raised beyond the necessary working heat. On big work, where much heat is required to bring the metals to the proper temperature for efficient soldering, it is better practice to use a large pot carrying a large charge of solder at about the usual soldering temperature of the solder rather than to use a small pot and raise the temperature of the solder unusually high.

As the temperature is raised, the metals exposed to the action of oxygen in the air are oxidized unless protected by a hard soldering flux such as powdered borax, charcoal, soda, etc.

Tin is much lighter than lead and rises to ~~the~~ top of the pot unless the pot is properly stirred. The greatest losses by oxidation due to overheating solder are tin losses, though part of the lead is oxidized as litharge.

When it is necessary to raise the heat on solder unusually high for any reason (as when the pot has to be carried a relatively long distance), the metal should be covered with a hard soldering flux.

Stirring and skimming a pot of overheated solder are not recommended because of excessive loss by oxidation.

In the consideration of fluxes attention must be paid to the kind of metals to be joined and their massiveness. Ordinarily it takes more heat to solder iron or steel than is required for soldering lead. When a soldering iron is used, the heating may be too localized if the heat is conducted away rapidly, consequently the iron must be exceptionally hot. In such a case, rosin may be unsatisfactory as flux because the heat tends to carbonize it, thereby preventing good soldering. When soldering large pieces of metal together, it is nearly always desirable to pre-tin parts individually before assemblage for soldering. This facilitates the soldering and makes stronger joints. Before soldering cast iron, a cold pickling bath of 5% hydrofluoric acid is recommended.

Pastes or powders composed of pulverized tin or solder mixed with flux are on the market and used to some extent. Tubular solder wire with a core consisting of rosin or other flux is quite popular. Adequate amounts of solder should be used in joints but economy demands no more than enough. To attain this end more expensive solders containing more tin are sometimes used because they flow better and less is required. Special forms and small sizes of solders are marketed to

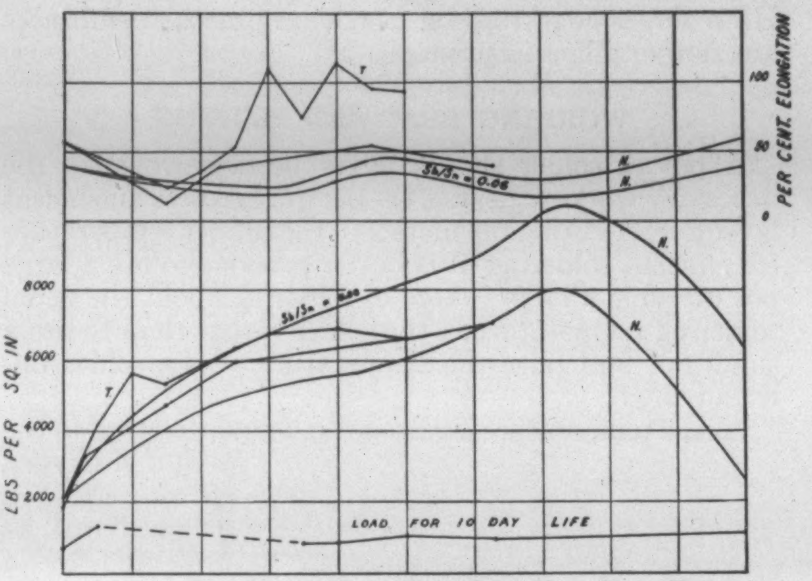


Fig. 2.

aid the consumer in getting just the right amount of solder in a joint. Forms obtainable are tinner's bar, triangular bar, meter bar, ingot wire in spools or in segments, drops, capping bar, slabs, pulverized and tape or ribbon.

The time required in making a good soldered joint may be extremely short. While prolonging of the period of time in which the solder is molten in a joint may increase the amount of alloying, the effect is not considered beneficial. When soldering copper, it is advisable to use temperature below 400° C. (750°F) in order to prevent the formation of a copper-tin compound Cu_3Sn which is brittle and tends to reduce the strength of the joint when present.

MECHANICAL PROPERTIES

Nightingale says that the antimony content should be restricted in the solder for dipping of brass and copper articles, claiming that the antimony should be just 1% of the tin content as when the ratio is either higher or lower than this, there is a formation of a larger quantity of coppery dross. He favors the use of antimony in most solders but mentions that when it exceeds 6% of the tin content, cubes of the antimony-tin gamma solid solution appear. Their presence is undesirable owing to the brittleness they impart to the solder. His tests show 0.003″ for a desirable thickness of a solder film on copper and 0.005″ for steel. Crow[20] previously indicated that the thinner the solder film the stronger the joint.

In Fig. 2, results are presented showing the ultimate tensile strength and elongation for four series of solder alloys. Two of the series marked N. represent Nightingale's work.[37] In one series, the alloys were made from tin containing 6% antimony, therefore, in this series at the lead end, there is no antimony but at the tin end, there is 6% and the 50-50 alloy contains 47% tin, 3% antimony, 50% lead. His results show an appreciable increase in strength due to the addition of antimony. The series marked T. tested by Thompson[39] and the series without mark representing test results obtained at the National Lead Company Research Laboratories are somewhat in agreement with Nightingale's results as illustrated. Nightingale and Thompson used special molds for casting the test bars to size. In the fourth series, the alloys were cast to size in the steel mold making round bars of 2″ gage length and 0.505″ diameter. These were pulled at rates corresponding to 0.026″ and 0.5″ per minute travel of the free cross head of the testing machine, respectively, to the yield point (0.5% elongation) and thereafter.

At the lower part of Fig. 2, test data are presented, described as load for ten day life. These data are chosen from some investigations under way and were obtained by the use of cast sheet specimens 1/8″ thick which were punched to standard tensile strength specimen form 2″ test length and 1/2″ wide. The specimens were supported from a test rack with weights hanging from the lower ends of the specimens. While the specimens were not entirely free from vibration during test, it is felt that the results are comparative among themselves. These data are striking in comparison with the quick pull strength values as shown in the upper part of the diagram. In addition to the strength of specimens for ten day life of lead-tin alloys, two other alloys containing antimony were tested and the following results found:

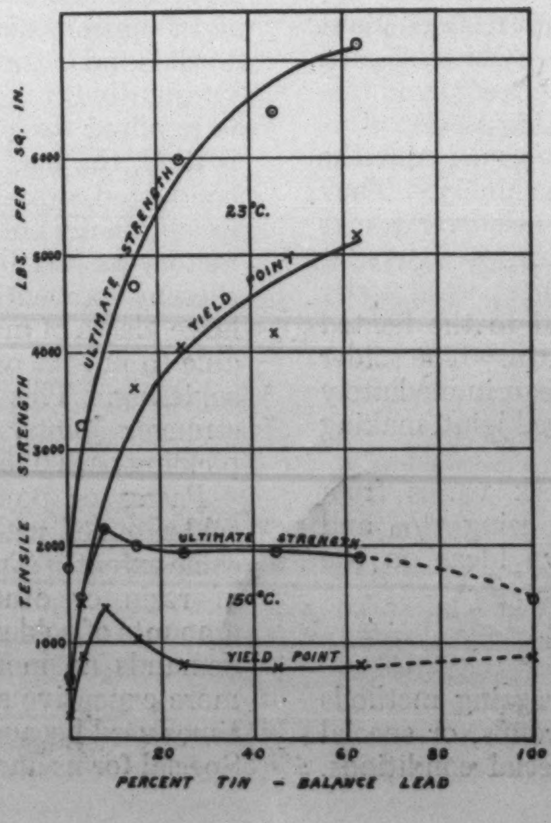
Load for Ten Day Life of Cast Metal

Lead	Tin	Antimony	lbs./in.²
47	53	...	1,000
47	50	3	1,080
57.6	42.4	...	900
57.6	40	2.4	1,030

The advantage of increased strength due to the addition of antimony is not so evident here as in the quick pull tests made by Nightingale.

As yet, we have no good data for the maximum load solder alloys will sustain for an indefinite period. Freeman and Quick[26] have presented some data on the flow of extruded and drawn wires under a continuous load. They also tested some soldered strips under continuous load. A more recent investigation[40] conducted at the Bureau of Standards gives the results of a study of lap seams for copper roofing. It was decided that the seams should be at least 3/4″ wide. The maximum safe load for soldered lap seams was placed at approximately 350 lbs./in.² (length times width) of seam, and for 1/2″ pretinned flat lock seams 375 lbs./in.² of seam. A 50-50 solder was used in these tests.

Fig. 3 presents the ultimate tensile strength values as illustrated in Fig. 2 but the results are now used in comparison with



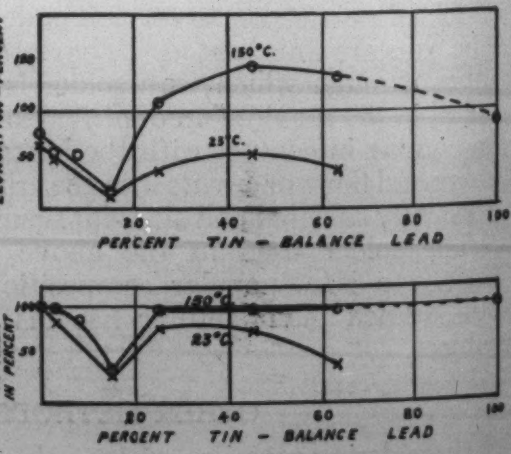


Fig. 3. Physical Properties of Lead-Tin Alloys.

data for the strength of the alloys at 150° C. The loss in strength at first appears remarkable but on consideration of the equilibrium conditions in the alloy system, the results are not surprising as 150° C. (302° F.) approaches the eutectic temperature, 181° C. (358° F.), at which the alloys containing from 18 to more than 63% tin would have practically no strength.

After these tests had been conducted, a further investigation was made of the life of several alloys under a continuous load of 100 lbs./in.[2] with rising temperatures. These results are depicted in Fig. 4. The specimens were in sheet form 1/16″ thick produced by casting in a steel mold. They were then cut to small specimen size as illustrated in Fig. 5. The test section was 1/8″ wide. The holes used for suspension were reinforced with copper eyelets. These specimens with weights attached were suspended in molten paraffine. In the first heating test, I., alloys containing 3 and 8% tin were found to be so resistant to flow at elevated temperatures that they were reinvestigated in duplicate in heating test, II.

These data on strength at room temperature and elevated temperatures have been presented more for a matter of interest than for use as conclusive results. Just how far they can be applied to practice is somewhat problematical at this time although it is hoped the reader will agree that they will be useful in a general way and that the trend of the investigation is in the right direction. In consideration of the strength of soldered joints, one must make allowance for a safety factor needed on account of imperfections in joints which, unfortunately, frequently cannot be detected without destroying the joint. The possibility of the use of X-rays to examine joints for soundness might be considered.

An attempt has been made to give some general information on solders and their usage. In addition, some data have been presented on the strength of solders. Since much more is known on this subject than can be here given, a rather extensive bibliography is appended so that readers desiring to pursue this study further may do so more readily. The article by Nightingale[37] is particularly noteworthy.

Acknowledgment is gratefully made to Mr. W. A. Cowan for kind help in the preparation of this text and to Mr. C. H. Hack for the conductance of the creep tests.

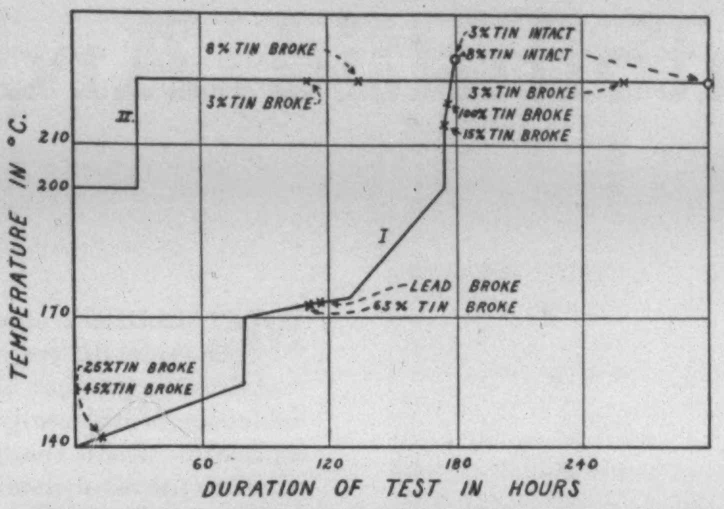


Fig. 4. Two Heating Records with Loci of Creep Failures of Lead-Tin Solder Cast Specimens under a Sustained Tension Load of 100 lbs./in.[2]

REFERENCES

[1] C. O. Bannister & H. J. Tabor Surface Appearance of Solders. *Journal Institute of Metals*, Vol. 2, 1909, page 58.

[2] Report of Committee on Standards of American Chemical Society. Solder Specifications. *Journal Industrial & Engineering Chemistry*, Vol. 3, 1911, page 860.

[3] C. W. Hill. Solder without Tin. *Chemical & Metallurgical Engineering*, Vol. 19, 1918, page 170.

[4] Anonymous. Solders and Substitutes for Lead-Tin Solders. *Metal Industry*, New York, Vol. 16, 1918, page 412.

[5] C. P. Steinmetz. Low Melting Eutectic Alloys. *Journal American Chemical Society*, Vol. 40, 1918, page 100.

[6] Symposium on the Conservation of Tin. *Transactions American Institute of Mining & Metallurgical Engineers*, Vol. 60, Non-Ferrous, 1919, pages 162–199.

[7] E. H. Schulz. Solder Alloys. *Das Metall*, Dec. 10, 1919, pages 313–316.

[8] Hill & Carpenter. Cadmium Solder. *Metal Industry*, New York, Vol. 17, 1919, page 82.

[9] *Bureau of Standards Circular* No. 78, Solders for Aluminum, Jan. 28, 1919, 9 pages.

[10] N. Parravano & A. Scorticci. Lead-Tin Solder. *Gazzetta chimica italiana*, Vol. 50, I, 1920, pages 83–92; F. A. Kartak. Solder, Soldering Flux and Soldering. *Metal Worker, Plumber and Steamfitter*, Vol. 92, June 1919, pages 162–164.

[11] C. W. Hill, T. P. Thomas & W. B. Vietz. Fluxes. *Transactions American Institute Mining & Metallurgical Engineers*, Vol. 61, 1920, page 668.

[12] E. Andrew. Effect of Impurities in Solder. *American Machinist*, Vol. 54, 1921, page 841.

[13] Leon Guillet. Lead-Tin Solders. *Revue de Métallurgie*, Vol. 18, 1921, pages 758–760.

[14] H. Schulz. War Experience with Soft Solders. *Metal Industry*, London, Vol. 18, June 10, 1921, pages 443–444.

[15] L. Sterner-Rainer. A Study of Solders. *Zeitschrift für Metallkunde*, Vol. 13, 1921, pages 368–379.

[16] Gilbert. Lead-Tin Solders, Volume vs. Temperature. *Zeitschrift für Metallkunde*, Vol. 14, 1922, pages 247–249.

[17] Goebel. Lead-Tin Alloys. *Zeitschrift für Metallkunde*, Vol. 14, 1922, pages 357–366.

[18] S. R. Gerber. Hot Tinning. *Metal Industry*, London, Vol. 20, Feb. 1922, pages 65–68.

[19] T. B. Crow. Fluxes for Soft Soldering. *Transactions Faraday Society*, Vol. 20, 1924, page 199.

[20] T. B. Crow. Some Properties of Soft Soldered Joints. *Journal Society Chemical Industry*, Vol. 43, 1924, page 65T.

[21] A. Greig & H. Heape. Fluxes for Soft Soldering. *Transactions Faraday Society*, Vol. 20, 1924, pages 206–207.

[22] T. B. Crow. Soldering Fluxes. *Brass World*, Vol. 21, 1925, page 39.

[23] R. B. Deeley. Zinc-Cadmium Alloys. A Note on Their Shear Strengths as Solders. *Journal Institute of Metals*, Vol. 34, 1925, pages 193–206.

[24] *British Engineering Standards Association Specification* No. 219, Soft Solders, 1925.

[25] T. B. Crow. Some Experiments on the Soft Soldering of Copper. *Journal Institute of Metals*, Vol. 35, 1926, pages 55–70.

[26] Freeman & Quick. Tensile Properties of Soldered Joints under Prolonged Stress. *Metal Industry*, London, Vol. 24, Jan. 1926, pages 7–10.

[27] E. T. Richards. The Practical Evaluation of Soft Solders. *Brass World*, Vol. 23, 1927, page 361.

[28] R. S. Dean & R. V. Wilson. Action of Fluxes in Soft Soldering and a New Class of Fluxes for Soft Soldering. *Industrial & Engineering Chemistry*, Vol. 19, 1927, page 1312.

[29] A. W. Coffman & S. W. Parr. Surface Tension of Metals with Reference to Soldering Conditions. *Industrial & Engineering Chemistry*, Vol. 19, 1927, page 1308.

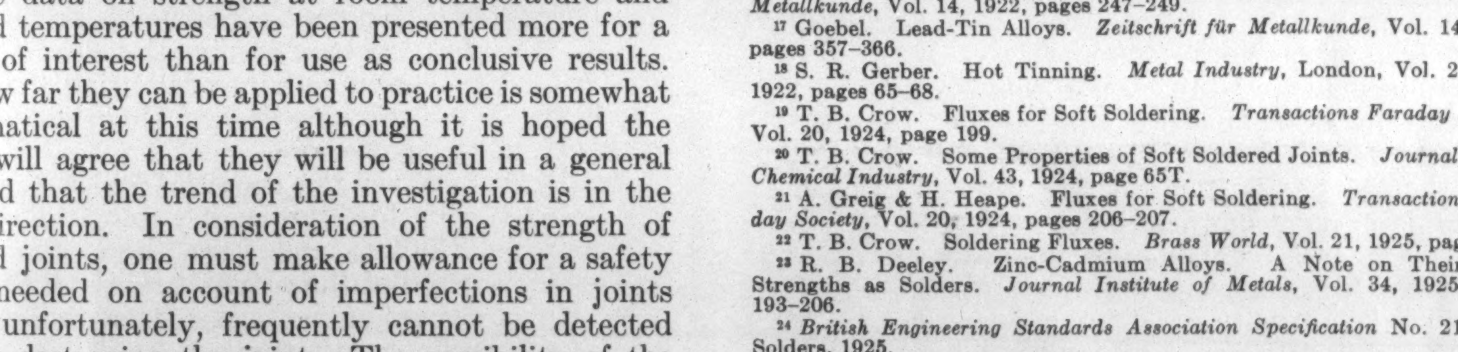
[30] Anonymous. Solder for Various Metals. *Brass World*, Vol. 24, 1928, pages 189–190.

[31] C. H. M. Jenkins. The Strength of a Cadmium-Zinc and a Tin-Lead Alloy Solder. *Journal Institute of Metals*, Vol. 40, 1928, page 21.

[32] C. E. Swartz. A Study of Certain Alloys of the Lead-Tin Cadmium System with Reference to Their Use as Solders. *American Institute of Mining & Metallurgical Engineers, Proceedings Institute of Metals Division*, 1928, pages 353–368.

(Continued on page 277)

Fig. 5.



Automatic Arc Welding

BY A. M.

METALLURGY classes as one of the "exact sciences," that is, if you really do the same things to a metal twice, you get the same results both times. The difficulty is in really reproducing conditions exactly, especially when the product cannot be tested to tell whether the result has been the same, without destroying the material. Nowhere in the application of metallurgical products is the task of obtaining true uniformity harder than in the case of welds.

AUTOMATIC arc welding has found its major application in the manufacture of various articles from steel sheets. These products include pipe, tanks, cans, boilers, machine parts, and structures used in the building trade and shipyards.

As a general rule such applications can be worked out economically with the greatest satisfaction since the welded seams are usually simple and of reasonable length. The work handling machinery for both the circular and straight seams can be designed to accommodate various sizes of work and thickness of plate with minimum delay for adjustment.

The advantages of automatic arc welding are summed up in the words economy and reliability. Higher welding current with resulting higher speed and electrode deposit is possible than by manual welding. No time delay is introduced in changing electrode rods since the electrode is a wire fed in long lengths or from a coil. These factors enable an automatic weld to be made in $^{1}/_{3}$ to $^{1}/_{6}$ the time required by a manual welder. The first figure holds for plates of $^{1}/_{4}$ or $^{3}/_{8}$ inch thickness while the greatest time saving is effected on the thinner sheets. Greater general reliability is obtained since the weld is made without interruption and since the arc voltage is maintained more constant than is possible in hand welding.

Fig. 1 shows an automatic welding head developed by the Westinghouse Electric and Manufacturing Company for all forms of metallic arc welding. The electrode wire of any diameter up to $^{5}/_{16}$ inch is automatically drawn from the reel and fed to the arc. In the illustration the wire is shown entering the guide to the feeding rollers from the top and emerging from the lower end of the long nozzle. The nozzle serves the purpose of guiding the electrode to the seam and transmitting the welding current to it through the sliding contact in the bore.

When the operator pushes the "start" button, the head automatically strikes the arc and feeds the electrode downward at the required rate to maintain the desired arc voltage. It continues to weld without interruption until the operator pushes the "stop" button or until the electrode wire is consumed. The welding current is adjustable at the welding generator or welding outlet panel and the travel speed is adjustable at the work handling machine. The head itself is a small tool which may be mounted on a moving carriage together with the electrode reel to produce a weld on work that is held stationary. It may also be mounted on a stationary support and the work moved under it in a direction parallel with the seam. Both forms of welding are found in the applications illustrated below.

A quite recent application of automatic welding on steel plates is in connection with "Battledeck"

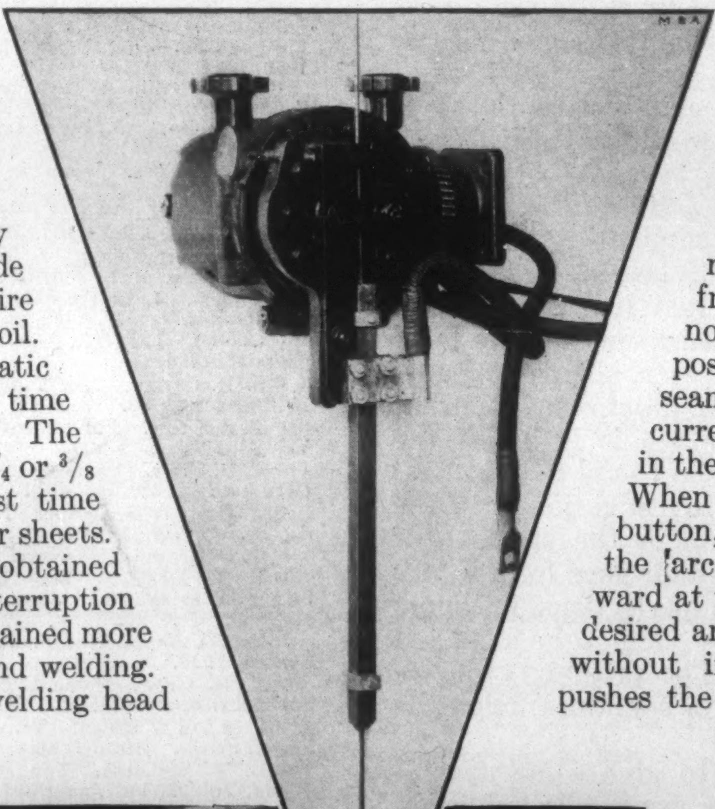


Fig. 1. Westinghouse Automatic Welding Head.

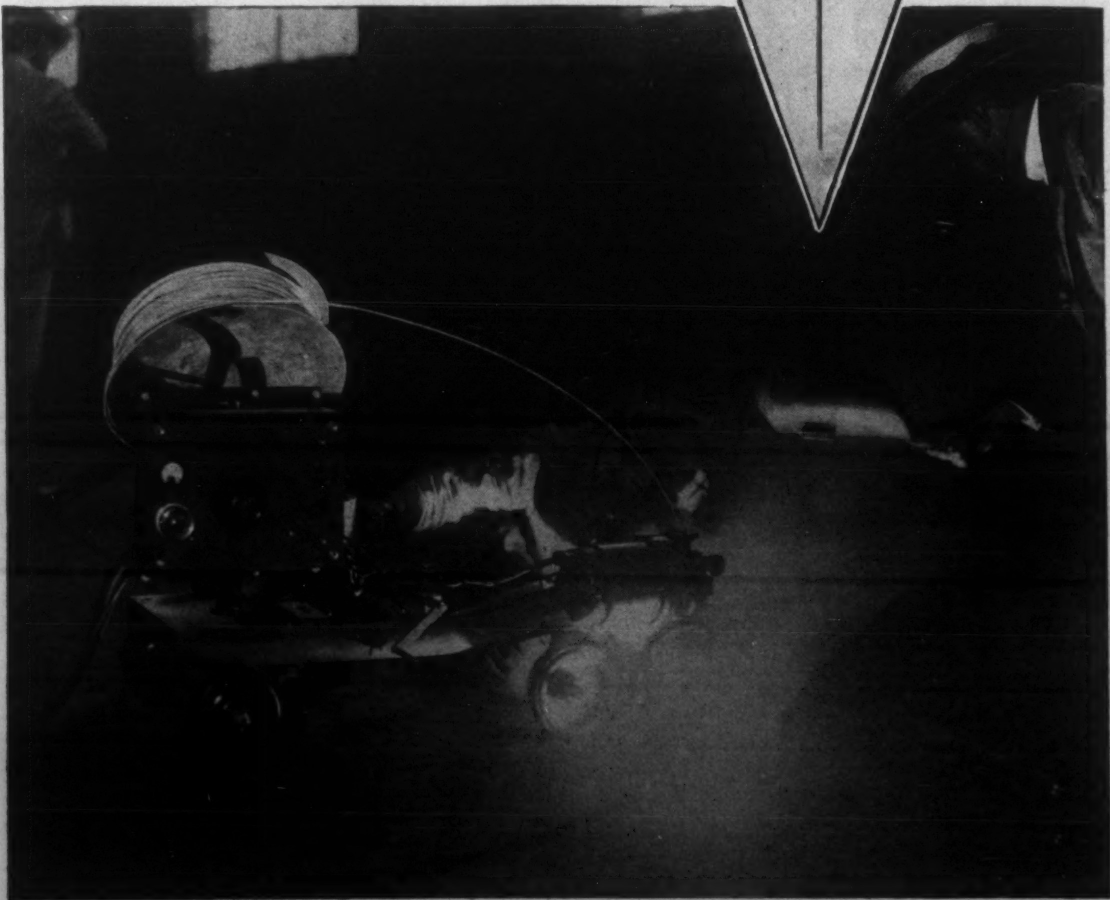


Fig. 2. Automatic Welding Tractor for Steel Floor Plates.

---

* Welding Engineer, Westinghouse Electric & Manufacturing Company.

# of STEEL SHEETS

CANDY*

The human element is primarily responsible for the variations. Where hand welding must still be resorted to, "procedure control" or the attempt to control the variables, is steadily being improved, but wherever the job can be done mechanically, the chances for uniformity are much increased. Several automatic welding methods, worked out with uniform quality of weld as the primary goal, and speed of welding as a secondary one, are described in this article.

floor construction for buildings. This new method makes use of steel plates welded to the floor beams of a building to produce a fire resisting construction. The stiffening and bracing effect of the plates welded to the I beams together with the considerable weight reduction as compared with concrete floor panels permits the use of lighter main steel members and eliminates some expensive concrete form construction. Fig. 2 shows the use of an automatic welding head on a self-propelled tractor designed to follow the plate joint over a floor beam and to weld two adjacent plate edges to the beam.

A similar tractor can be used to weld plates and structural members for oil storage tanks, ships and barges.

Fig. 3 shows an automatic welding application in the assembly of small safety coil tanks; the work consists of one deep drawn shell with terminal outlets forming the top and sides of the tank. The flanged bottom is pushed into the tank shell and the joint is sealed with a fillet weld as shown in Fig. 4. The weld is made after the tank is loaded with its coil parts and filled with insulating gum. A special type of handling machine was developed to provide ease of loading and unloading and adaptability to a range of lengths and diameters. The bed of the machine is mounted on trunnions to permit welding at the most desirable angle and to present either end of the tank to the arc without inverting the tank. The driving element consists of four parallel flanged supporting rollers on two shafts driven by an electric motor through a gear train. By using this driving system it is necessary only to place the cylinder on the rollers to prepare it for the welding operation. The peripheral or welding speed remains the same for all diameters with one adjustment.

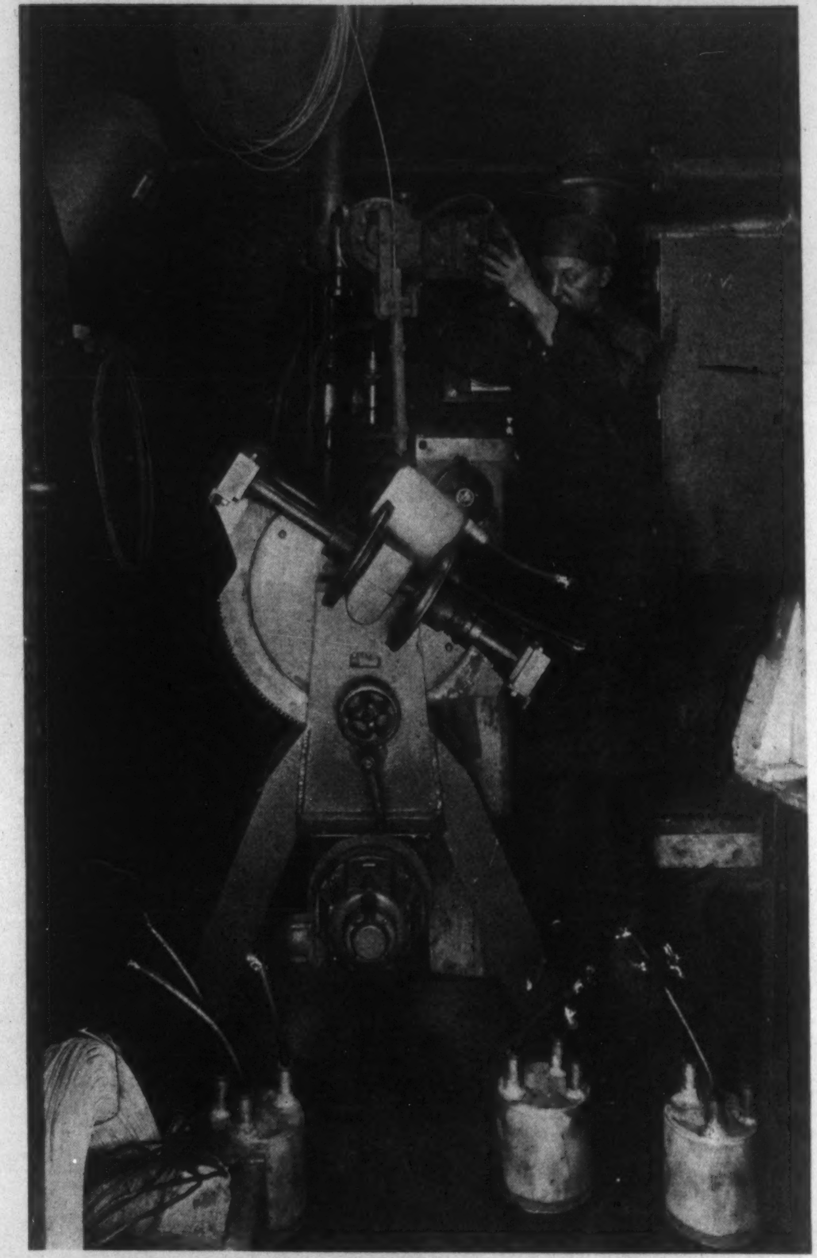


Fig. 3. Manufacture of Safety Coils by Automatic Welding.

Fig. 4 indicates the quality of the weld obtained with the automatic arc at the bottom of the tank. The weld is completed in 54 secs. compared with a welding time of 7 minutes by hand. A welding current of 140 amperes and $^{1}/_{8}$-inch diameter electrode is used to complete the seam on No. 14 gage material at a welding speed of 140 ft. per hour. A speed of 200 ft. per hour could be easily obtained with increased welding current at a slight sacrifice in appearance.

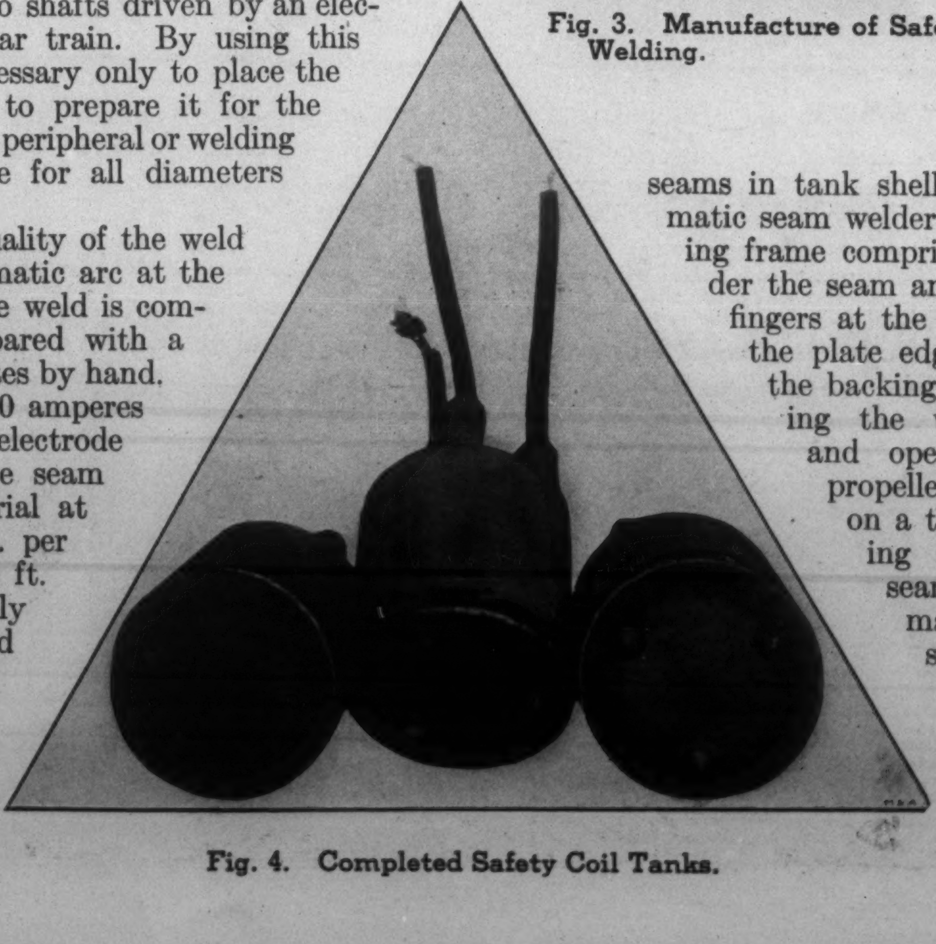


Fig. 4. Completed Safety Coil Tanks.

The most universal tool in use for butt or lap welding straight seams in tank shells or plates is the automatic seam welder. It consists of a clamping frame comprising a backing beam under the seam and air pressure clamping fingers at the side of the seam to hold the plate edges down in line against the backing bar. A carriage mounting the welding head, wire reel and operator's controls is self-propelled at any desired speed on a trackway over the clamping arms parallel with the seam. Fig. 5 shows such a machine in use to weld the side seam in several elliptical tanks which are held in the clamp simultaneously.

Fig. 6 shows a modern machine of this type in greater detail.

It is particularly adaptable for relatively low production shops since it will accommodate a large range of tank or pipe diameters and plate thicknesses without adjustment. Moreover it can be used to butt or lap weld two straight plates together under clamping pressure.

Fig. 7 shows a transformer shell with the longitudinal seam butt welded in a seam welder. The material is $^1/_8$ inch thickness steel and was welded at the rate of 70 ft. per hour using $^5/_{32}$-inch diameter electrode and 225 amperes.

Steel sheets as thin as 22 gage have been butt welded in a clamp seam welder with good results and at commercial speeds. A welding speed of 160 ft. per hour is readily obtained on work of this kind. It is usually considered impractical to try to weld sheets thinner than 14 gage with the manual arch, therefore automatic methods open a new field for arc welding sheets of lighter than 14 gage, with maximum economy and minimum distortion in the work material.

A large percentage of the gas and oil pipes which are now spanning the country to carry our natural resources from the fields to centers of consumption are manufactured by automatically arc welding the longitudinal seams in bent sheets. Another form of pipe popular for its lightness, flexibility and strength is shown in Fig. 8. This pipe has a spiral seam mechanically locked and welded. It is manufactured in quantities measured in miles per day by automatic arc welding. A rust resisting steel is used in its manufacture to combine long life with light weight.

An attachment for standard welding heads is available to permit semi-automatic welding on irregular seams. This device is shown in Fig. 9 attached to the nozzle holder of a head such as shown in Fig. 1. The electrode wire is drawn from the reel and fed to the arc in exactly the same manner as for automatic welding but in this case the greater portion of the nozzle is flexible so that the end near the arc may be manipulated by the opera-

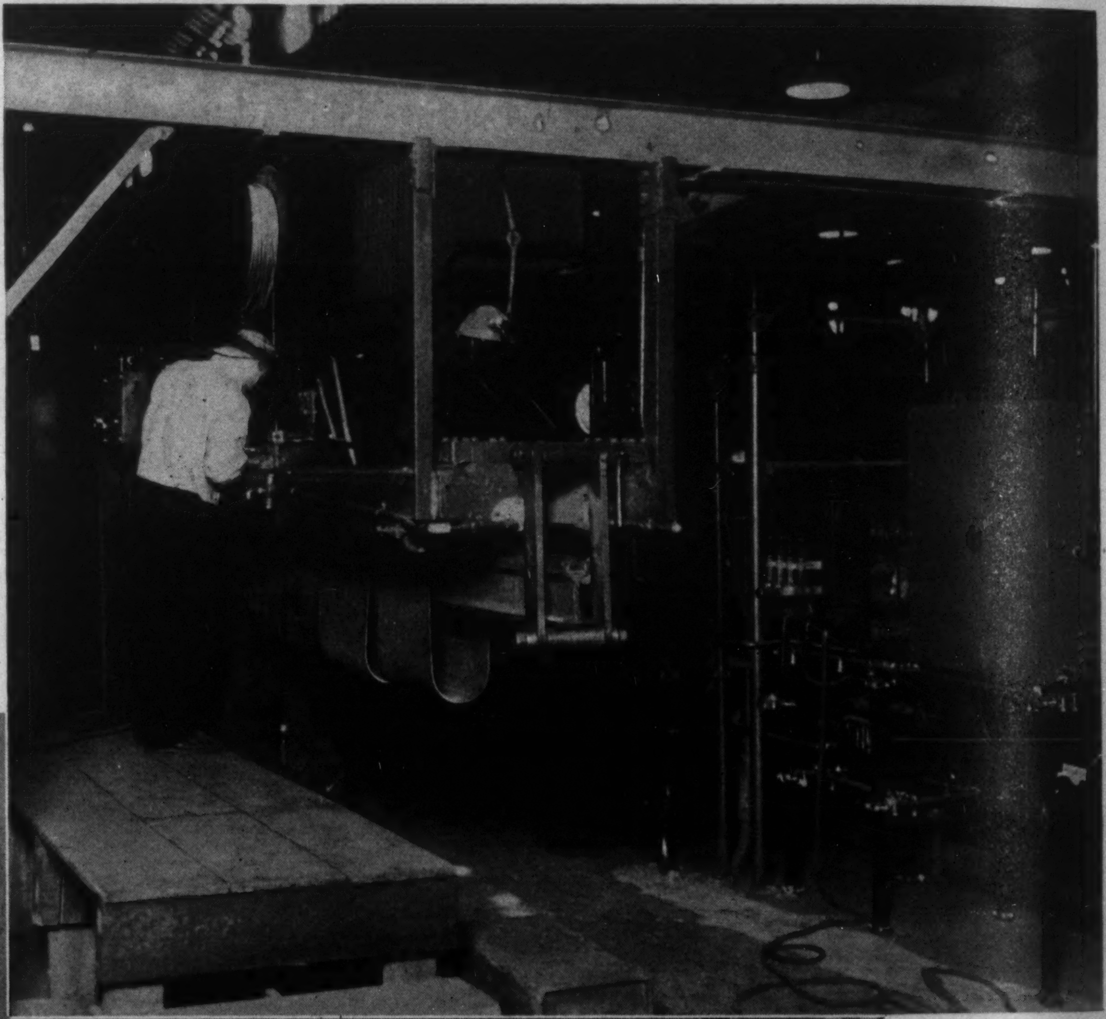


Fig. 5. Automatic Seam Welder for Tank Shells and Plates.

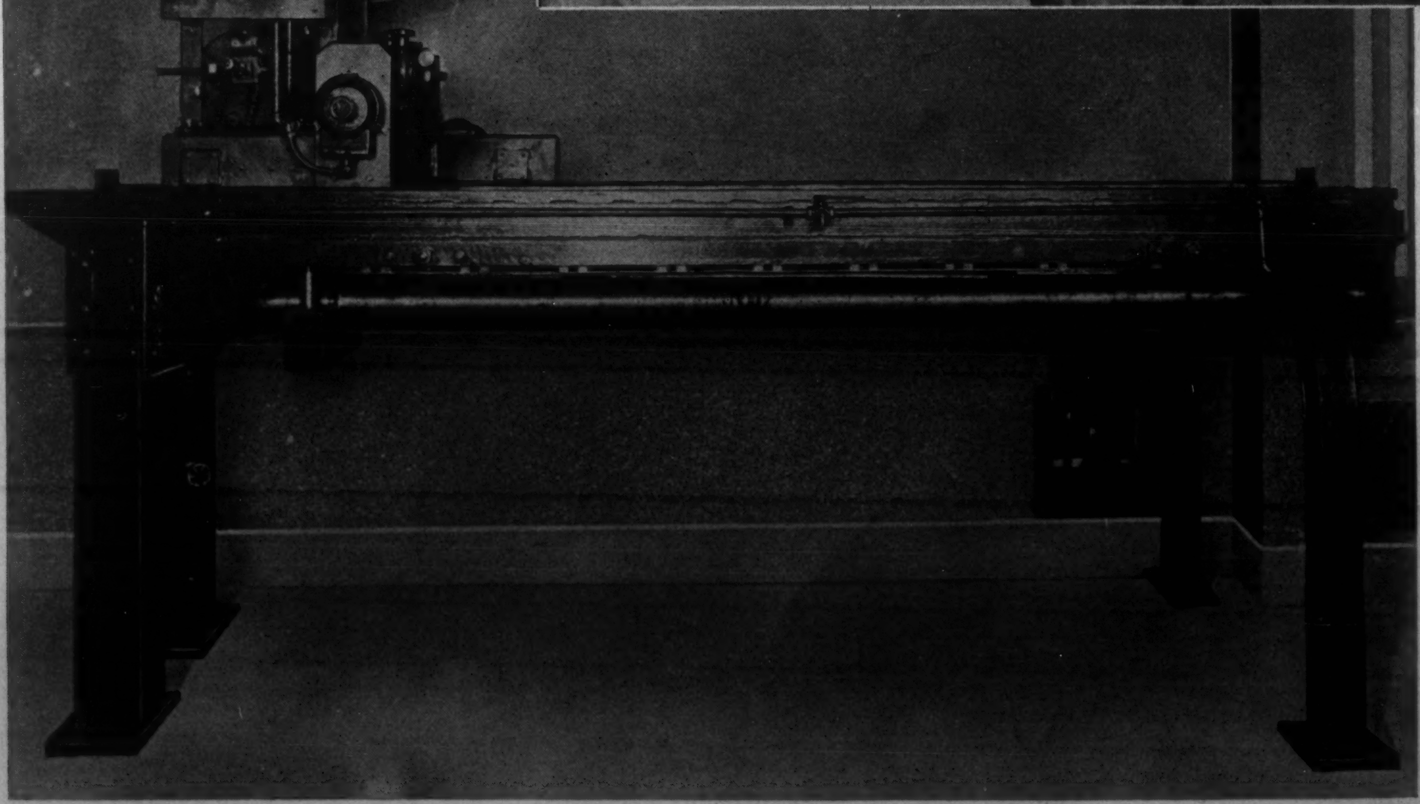


Fig. 6. Westinghouse Eight Foot Seam Welder.

tor to follow the seam. The head and work are usually held stationary during the welding operation.

The holder or arc end of the nozzle is provided with a fiber handle, arc shield and trigger switch to start and stop the arc and wire feed. The welding current enters the electrode largely through the sliding contact in the rigid nozzle portion at the holder. The flexible nozzle portion between the holder and the head is made up of a hard flexible steel core covered with fine copper braid to conduct the welding current to the holder. An insulating cover of rubber and cotton protects the copper braid against short circuit arcs to ground.

When the holder is suspended from the head, as shown in the illustration, it may be guided about over a considerable area while the head is feeding the electrode wire downward through the nozzle and maintaining the arc. This is an ideal condition for semi-automatic welding since the weight of the holder is carried from the head and the arc is struck and maintained without assistance on the part of the operator. He merely guides the holder along the seam at the proper speed to obtain the desired fusion and electrode deposit. Under these conditions an inexperienced welder can learn to make very good welds in a short time. Increased production of more than 100% can be obtained on work that lends itself to this arrangement. This includes tank tops having irregular seams and work of a similar character in which the weld is confined to a limited area in a horizontal plane. On large areas the head should be mounted on a moving support so that it may be moved along over the seam at intervals.

On work requiring one or more sharp bends in the flexible nozzle tube between the head and holder some of the advantages of this ideal case of semi-automatic welding disappear. The operator must then support the weight of the holder end and maintain a reasonably constant distance between the end of the nozzle and the work. In this case the automatic welding head is solely an electrode feeding device. The time saving over straight manual welding is equivalent to the time lost by the hand welder in changing electrodes.

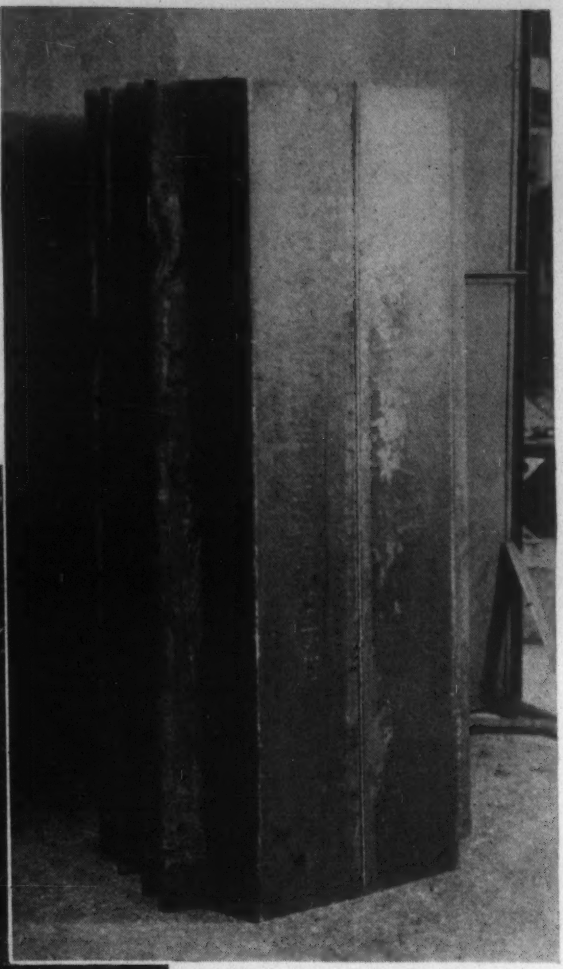


Fig. 7. Side Seam in Transformer Tank by Automatic Arc Welding.

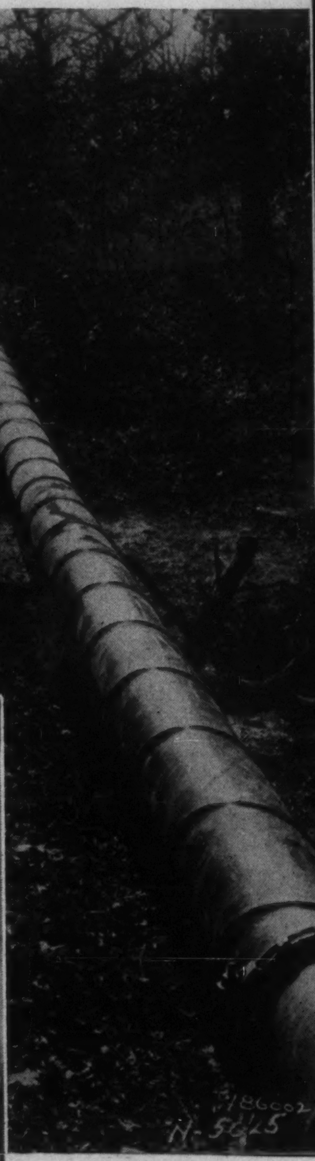


Fig. 8. Naylor Welded Pipe.

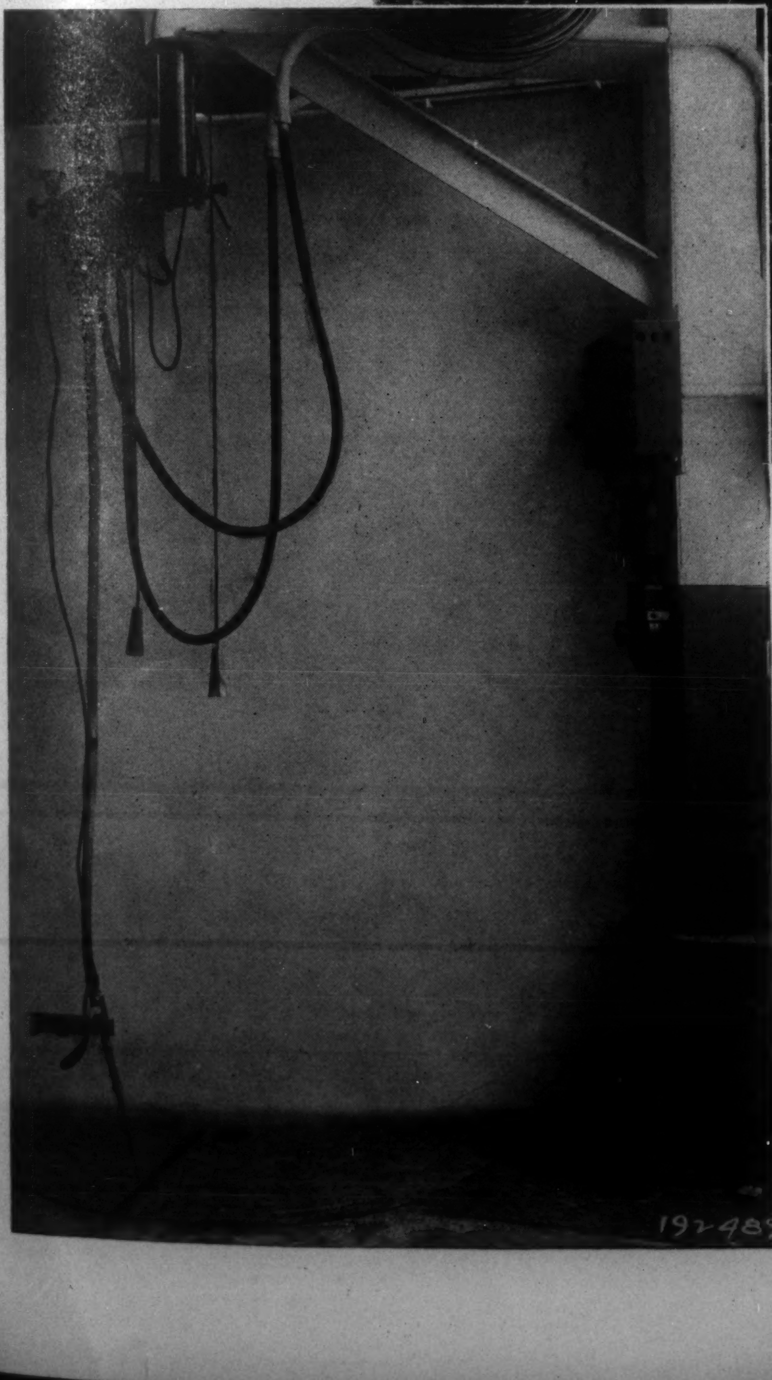


Fig. 9. Welding Head with Semi Automatic Welding Attachment.

◆

The Chrome Alloy Products, Inc., is now a subsidiary of The Midvale Company.

The Adherence of

BY WILLIAM H.

IN ANY discussion of the adherence of zinc coatings the subject naturally divides itself into two considerations, first, that of securing the adherence of molten zinc to bare iron or steel during the coating process and second, that of obtaining a coating which will subsequently withstand deformation without losing its adherence to the steel base.

The first problem is not particularly difficult, the second is anything but easy.

The ease with which zinc alloys with iron in the ordinary hot dip galvanizing process makes the securing of a continuous and adherent coating of zinc comparatively simple. If the surface of the iron or steel article has been properly prepared by pickling, and coated with a suitable flux, the molten zinc will readily "wet" it as soon as the base reaches the temperature of the zinc bath. Because of this property of readily "wetting" iron or steel, zinc has a distinct advantage over tin or lead in the hot coating process. The bothersome defect of pin holes so common to tin, terne and lead coated products is much less apparent in galvanized products and, even though a few pin holes do exist in these latter, the well-known electro-protective characteristics of zinc coatings with respect to iron under many service conditions will prevent rusting of the base either in these areas or where minor abrasions of the coating may have exposed it. The rusting between coating and base frequently observed along deep scratches or at pin hole points in tin, terne and particularly lead coatings, with some attendant exfoliation of the coating, never occurs in the case of zinc coatings.

However, this simple picture of zinc coating adherence is completely changed when the coating is deformed or stressed. The relatively low malleability and poor adherence of zinc coatings as compared with tin, terne or lead coatings has been one of the major problems confronting the producers of galvanized sheet and wire for many years since large tonnages of these products are subjected to severe deformation either in some fabrication process or in the course of their ordinary use. Until comparatively recent times the galvanizers had only one solution for this problem which was to reduce the thickness of the zinc coating. They discovered long ago that the malleability of zinc coatings increased as their thickness decreased and the practice of putting thin coatings on material which is to receive severe fabrication has been general throughout the industry. However, with the development of the Crapo process[1] to secure heavy coatings with good bending properties on iron wire, principally for telephone and telegraph use and the patented process[2] of heat treating wires and sheets immediately upon leaving the galvanizing bath, there are now available to the galvanizers methods of securing somewhat heavier zinc coatings on certain classes of products at no sacrifice in coating adherence. But the great bulk of wire and sheet products for severe fabrication service is still made with light coatings.

Although a study of the bending properties of zinc coated products has been made by many investigators on various occasions, the literature on this subject is very meager. The articles of Bablik[3] and the previously mentioned patents of Crapo and Herman contain most of the interesting information. While the fundamental principles controlling the adherence and ductility of zinc coatings are far from being well established, there are, however, certain factors which are known to have an influence on the production of ductile, adherent coatings in many cases. These are briefly discussed in the following paragraphs.

ZINC COATING STRUCTURE

The structure of zinc coatings is undoubtedly the most important single factor in determining their ductility and their adherence. But unfortunately our knowledge of the various structural features to be seen in the coatings and their relation to the properties of ductility and adherence is still too limited to warrant the drawing of very definite conclusions as to the exact part the structure of the coating plays in determining these properties.

Metallographic studies[4] of the structures of zinc coatings have been made and the iron-zinc alloy constituents of the coatings commonly identified as $FeZn_3$

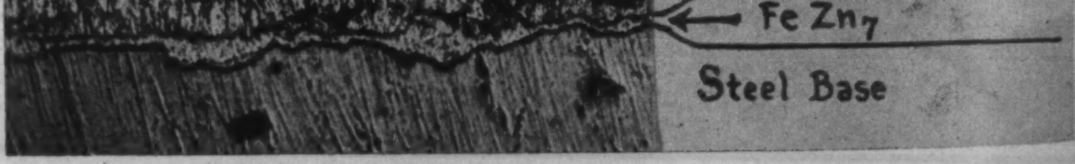


Fig. 1. Extra Heavy Zinc Coating. Mag. 350×.

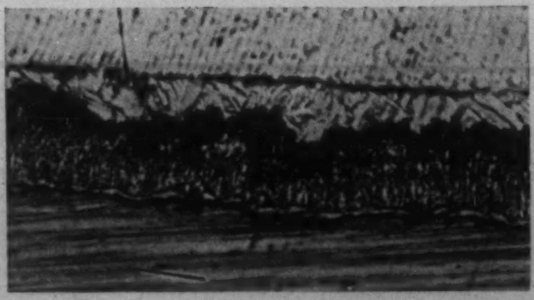


Fig. 2.

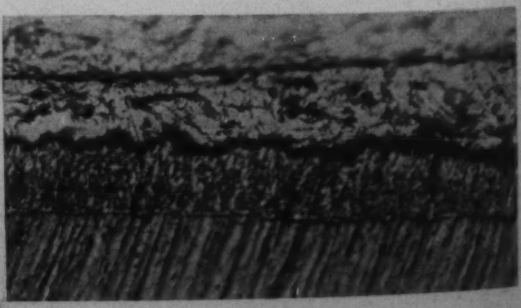


Fig. 3.

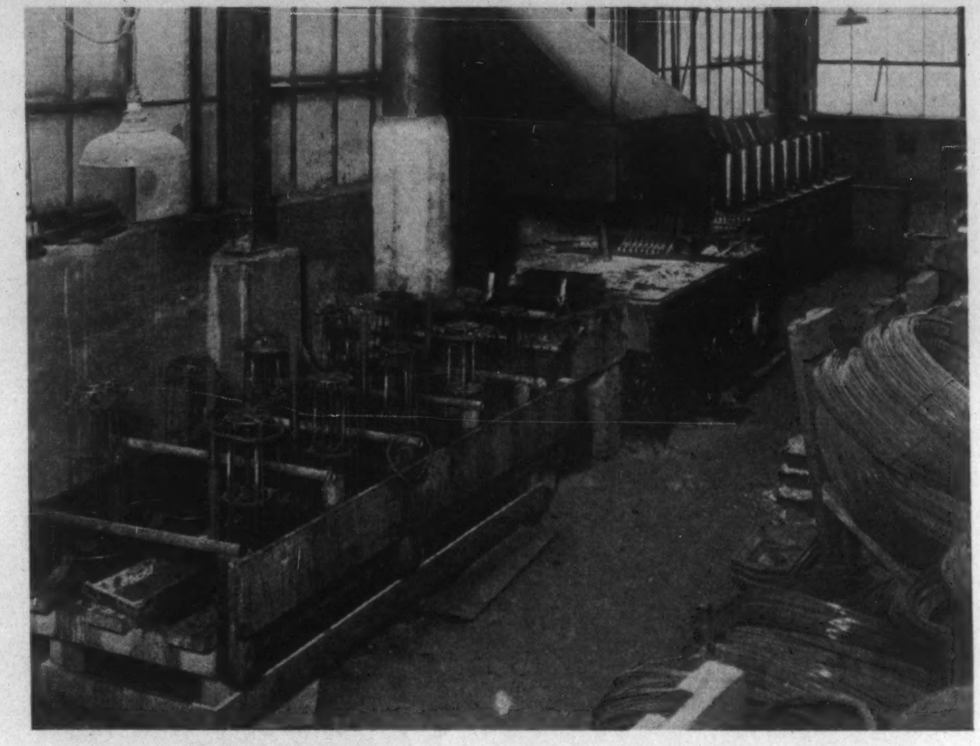
Typical Heavy Zinc Coatings on Pure Iron. Mag. 350×.

---

* Of Singmaster & Breyer, Consulting Engineers.

ZINC COATINGS

FINKELDEY*



Unit for Galvanizing No. 20 to No. 38 Gage Wire at Plant of Thompson Wire Co., Worcester, Mass. (Courtesy Sleeper & Hartley, Inc.) Fuel Oil Used for Heating Spelter.

and $FeZn_7$ on the basis of the information obtained from the iron-zinc equilibrium diagram.[5]

While it is questionable whether the compositions of the iron-zinc alloy constituents of the coating are exactly $FeZn_3$ and $FeZn_7$, convenience justifies their use.

The microstructure of an extra heavy zinc coating is shown in Fig. 1. Starting at the surface the various constituents of the coating are:

1. A relatively pure zinc layer containing a small percentage of iron (about 0.02%) in solid solution.
2. A duplex structure consisting of a zinc rich, iron-zinc compound (possibly $FeZn_{10}$) showing a rough irregular contact with the pure zinc layer with some dispersion of the compound in the zinc matrix. This band is more deeply etched, has a roughened appearance and frequently shows columnar-like crystals growing normal to the surface of the underlying alloy layer.
3. A dense, light colored layer of iron-zinc compound having the approximate composition $FeZn_7$. Although not visible in the above microstructure, a fourth constituent, the iron-zinc compound $FeZn_3$, is sometimes seen next to the base appearing as a narrow band darker in color than the compound $FeZn_7$ (see Fig. 5). It is seldom that all of these structural features are distinctly visible in any one coating and this fact is probably responsible for a different interpretation of the structure than that given above. Other investigators question the existence of the narrow, dark colored alloy layer (Fig. 5) and designate the bright, light colored layer as $FeZn_3$ and the band of columnar-like crystals, growing irregularly from its surface into the overlying pure zinc layer, the $FeZn_7$ alloy layer. Whatever the designation given to these various constituents, their presence or absence, their thickness and contour is the important consideration since they determine to a great extent the ductility and adherence of the zinc coating.

There is a wider variation in the structure of zinc coatings than is generally suspected. In some cases the band of rough appearing columnar-like crystals growing into the zinc matrix (constituent 2) is wide with a dense, bright narrow layer of $FeZn_7$ beneath it, Fig. 2. Again this band may be fairly even, Fig. 3, or have an irregular tree-like appearance, Fig. 4.

In Fig. 5 all the constituents are present, the pure zinc layer, the very uneven layer of iron-zinc compound more or less dispersed in the zinc, the narrow band of dense, bright light colored $FeZn_7$ and the still narrower band of darker colored $FeZn_3$. Often the layer of pure zinc may be absent or so thin as to be invisible as in the case of asbestos wiped wire, Fig. 6, or coatings heat treated after galvanizing, Fig. 7.

CHARACTER OF STRUCTURE INFLUENCES BENDING PROPERTIES

All of these iron-zinc alloys have relatively high strength, are hard but extremely brittle and readily fracture if the coating is severely deformed. With a material of this character forming a large part of the total coating and overlaid with a layer of cast zinc, with its relatively low ductility, it is not at all strange that most hot-dip galvanized coatings have a low malleability. In general coatings with a fairly even contour to the iron-zinc alloy layers, Fig. 3, show good bending properties and adherence while those with an irregular contour, Fig. 4 and 5, do not. Also, the thinner the alloy layer the better its adherence to the base. Light and medium weight coatings consisting entirely of iron-zinc alloy, Figs. 6 and 7, nearly always have excellent adherence.

Fig. 4. Mag. 350×.

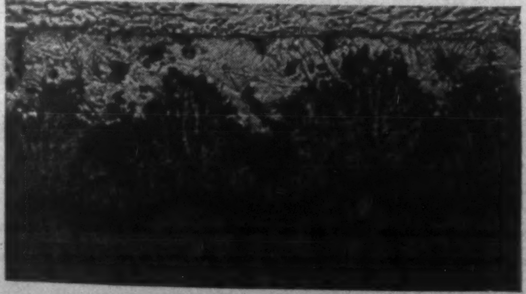
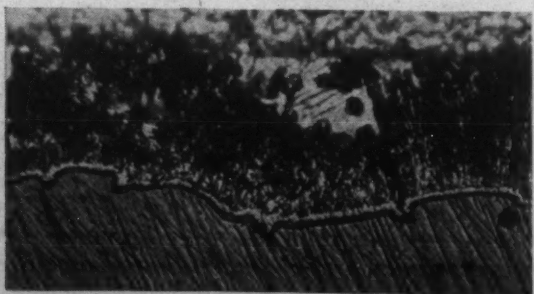


Fig. 5. Mag. 350×.



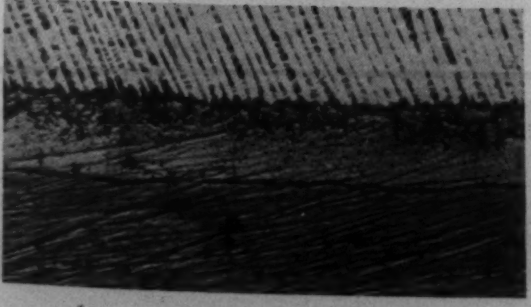


Fig. 6. Asbestos Wiped Wire Light Coating. Mag. 350×.

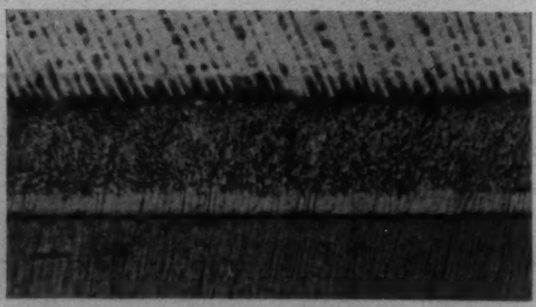


Fig. 7. Zinc Coating Heat-treated after Galvanizing. Mag. 350×.

FACTORS CONTROLLING THE GROWTH OF IRON-ZINC ALLOYS

The growth of these various iron-zinc alloy constituents is influenced by first, the temperature of the zinc bath, second, the length of time the base material remains in contact with the molten zinc, third, the time required for the coating to cool below 200° C. at which temperature the diffusion of iron into zinc is practically arrested, fourth, the chemical composition of the base and fifth, the composition of the zinc bath. Theoretically, these conditions can all be varied, some of them over a very wide range. However, practical considerations in the galvanizing operation seriously limit the possible variation of the first three factors. Nevertheless, despite this restriction imposed by operating conditions, considerable improvement in coating adherence and ductility can be effected through the control of the iron-zinc alloy growth.

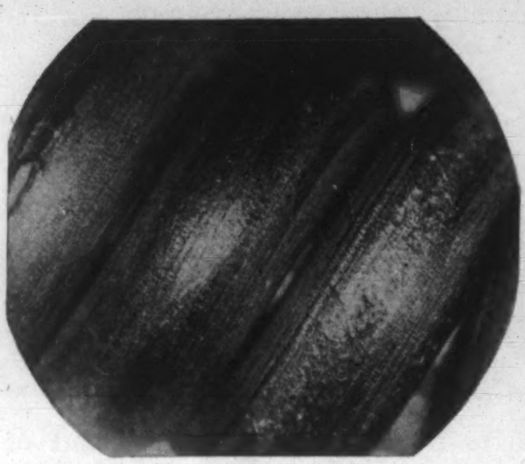


Fig. 8. Asbestos Wiped Light Coated Wire. Mag. 10×.

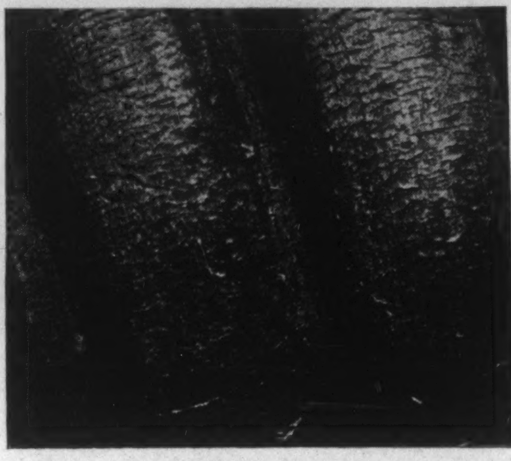


Fig. 9. Coating Heat-treated after Galvanizing. Mag. 10×.

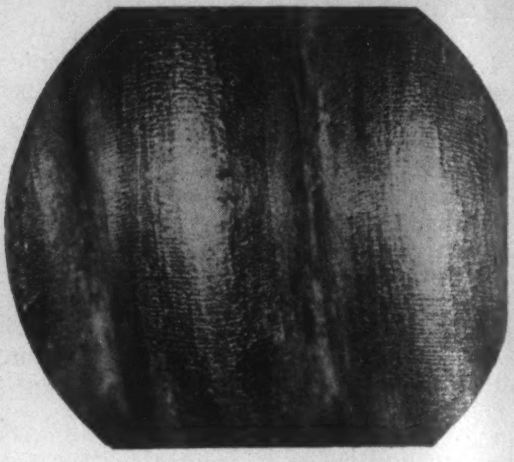


Fig. 10. Heavy Coated Wire Charcoal Wiped. Mag. 10×.

CRACKING NOT A CRITERION OF BENDING PROPERTIES

It is a common fallacy to believe that coatings with poor bending properties crack while those with good bending properties do not. As a matter of fact all zinc coatings crack when they are deformed. The real distinction between coatings classified as good and those classified as poor should be made, not on the basis of the degree of cracking which occurs, but on the basis of their adherence or non-adherence to base metal. Figs. 8, 9 and 10 show the surfaces of zinc coatings generally considered to have very good bending properties. The cracks apparent in the photographs are not readily visible to the naked eye.

In the case of coatings having good bending properties the stress apparently is relieved through the formation of numerous fine cracks, but the coatings show good adherence to the base (Figs. 11 and 12) while in the case of coatings having poor bending properties the cracks are fewer and larger, readily visible, and these coatings (Fig. 13) exhibit more or less peeling from the base metal in the region of the cracks.

UNIFORMITY AND THICKNESS OF COATING AFFECT ADHERENCE

As previously mentioned the thickness of zinc coatings has a marked effect on their adherence and malleability. As a rule, the thin coatings on the ordinary "tight" coated products, 0.3 to 0.4 oz. per square foot of surface with a thickness of about 0.0006″ show less serious cracking and peeling after severe deformation than the average heavy coated product running 1.0 oz. per square foot of surface 0.002″ thick (one side). The still heavier coatings found on hand dipped products such as nails, hardware articles, pipe and structural steel, which sometimes reach a thickness of 0.005″, 3.0 ozs. per square foot of surface, nearly always show bad cracking and spalling even with only moderate deformation.

It is to be expected that the uniformity of the coating would have an effect on its adherence. It is well known that the heavier (thicker) the zinc coating the greater is its non-uniformity, which may be a factor in explaining why heavy zinc coatings, as a general rule, have poor adherence. The following table gives some idea of the uniformity of coatings on light, medium and heavy coated sheets.

Wide variation in coating adherence at closely adjacent spots on the same sheet can usually be seen on such articles as leaders and gutters, special shaped railroad car roofing sheets and similar severly formed prod-

Weight of Coating Reported in Ozs. Per Square Foot of Surface and Separately Determined on Each Side of the "Nine Spot Test Specimens"

Sample No.	Type	Gage	1	2	3	4	5	6	7	8	9	Average	Min.	Max.
1	"Tight" coat	26	0.47	0.45	0.40	0.42	0.37	0.30	0.45	0.34	0.43	0.40	0.30	0.47
			0.44	0.37	0.40	0.36	0.42	0.47	0.35	0.31	0.39	0.39	0.31	0.47
												0.79		
2	Medium	26	0.68	0.58	0.57	0.57	0.50	0.55	0.60	0.45	0.60	0.56	0.45	0.68
			0.73	0.74	0.63	0.55	0.50	0.60	0.55	0.55	0.54	0.60	0.50	0.74
												1.16		
3	Heavy	26	1.02	1.06	1.02	0.86	1.23	1.27	1.06	1.06	1.06	1.08	0.86	1.27
			1.13	0.96	1.34	0.86	0.96	0.94	1.20	0.82	0.84	1.01	0.82	1.34
												2.09		

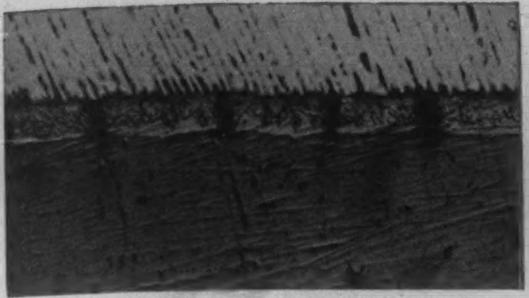


Fig. 11. Asbestos Wiped Wire.

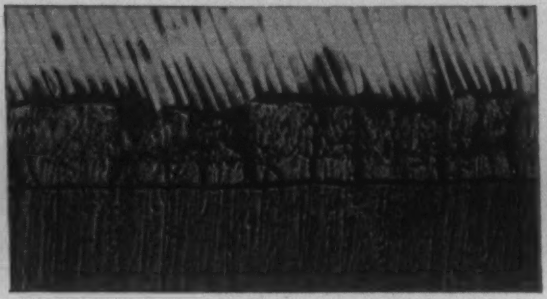


Fig. 12. Heat-treated Wire.

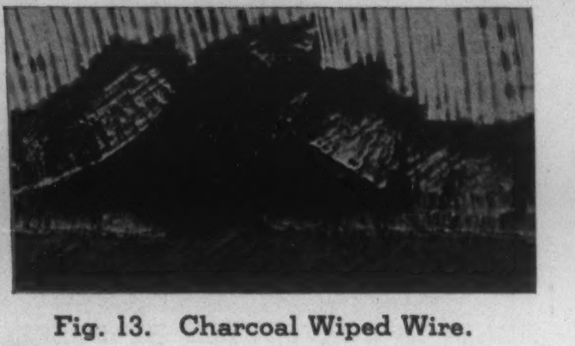


Fig. 13. Charcoal Wiped Wire.

Wires Wrapped on their own Diameter. Mag. 350×.

ucts made from galvanized sheets. While undoubtedly other factors play their part in causing this spot to spot variability in coating adherence, the question of coating uniformity should not be ignored.

COATING DUCTILITY AND ADHERENCE VARY WITH SPEED OF DEFORMATION

The rate at which the zinc coating is deformed is also a factor in determining its adherence. Most wire fence weaving machines, power driven brakes and forming presses fabricate the zinc coated articles at high speeds which places an added burden on the galvanizer in attempting to produce coatings with good bending properties. Very little is known regarding the physical and mechanical properties of the FeZn-alloy except that it is an exceptionally brittle material and as such would be very sensitive to the rate at which it is deformed. The more or less pure zinc layer overlying the iron-zinc alloy, we would expect to perform in a manner similar to ordinary zinc which exhibits wide variations in ductility depending upon its rate of deformation. Drawing further on our knowledge of zinc, we would naturally expect the malleability of galvanized coatings to show a similar sensitivity to the temperature at which the fabrication operation is carried out. The writer's experimental data covering this latter point is extremely scanty but it would appear to be a matter worth further investigation by the commercial fabricators of zinc coated articles.

ZINC BATH COMPOSITION AFFECTS DUCTILITY AND ADHERENCE

The chemical composition of the zinc bath in the hot galvanizing operation has a pronounced effect on the ductility and adherence of the zinc coatings produced. In the case of heavy coatings the physical properties of the pure zinc layer of the coating play an important part in determining the bending performance of the entire coating. Since very thin plates of cast zinc of high purity show a much greater ductility than similar plates cast from ordinary Prime Western spelter containing appreciable amounts of lead and cadmium, it is only to be expected that the purity of the zinc used in the galvanizing operation would have a marked effect on the bending properties of the coatings produced. This fact has been recognized by manufacturers of heavy coated telephone and telegraph wire, all of whom use "High Grade" zinc (lead less than 0.05%, cadmium less than 0.01%), and also by one producer of extra heavy coated sheets which subsequently are to be corrugated and fabricated into flumes and highway culverts. Where adherent coatings are required, Bablik[6] considers cadmium a detrimental impurity in the zinc bath since it has an accelerating effect on the growth of the iron-zinc alloy. His experiments indicate that the higher the cadmium content the thicker the iron-zinc alloy layers produced and the poorer the bending properties of the coating.

Aluminum is often added in small percentages (generally less than 0.01%) to the galvanizing bath to increase the fluidity of the molten zinc but such use has been confined chiefly to the galvanizing, by the hand dip process, of fabricated sheet metal articles such as buckets, ash cans, etc., because even the addition of these small amounts cause trouble from uncoated spots in the ordinary galvanizing of wire or sheets. However, within the last year a process has been patented[7] by one of the large sheet galvanizers covering the use of 2.5–8% aluminum in the zinc bath to secure coatings with good bending properties.

Tin is also added to sheet galvanizing baths, usually not in excess of 0.6%, to improve the brightness and appearance of the spangles on the sheet. Apparently this amount of tin has no marked effect on the formation of the iron-zinc alloy layers although it seems to have a slightly adverse effect on the ductility of the coating due probably to its embrittling effect on the pure zinc layer of the zinc coating.

BASE COMPOSITION A FACTOR IN COATING ADHERENCE

The chemical composition of the iron or steel base material is known to have an effect on the adherence of zinc coatings. For example, great difficulty is experienced in securing a ductile, heavy zinc coat on pure iron wire and steel wire of low carbon content while zinc coatings on wire having a carbon content of approximately 0.6% generally have excellent bending properties. There is also some evidence that the zinc coatings on rephosphorized steel of medium carbon content have good ductility and adherence. While no complete explanation has been offered for the presence of carbon

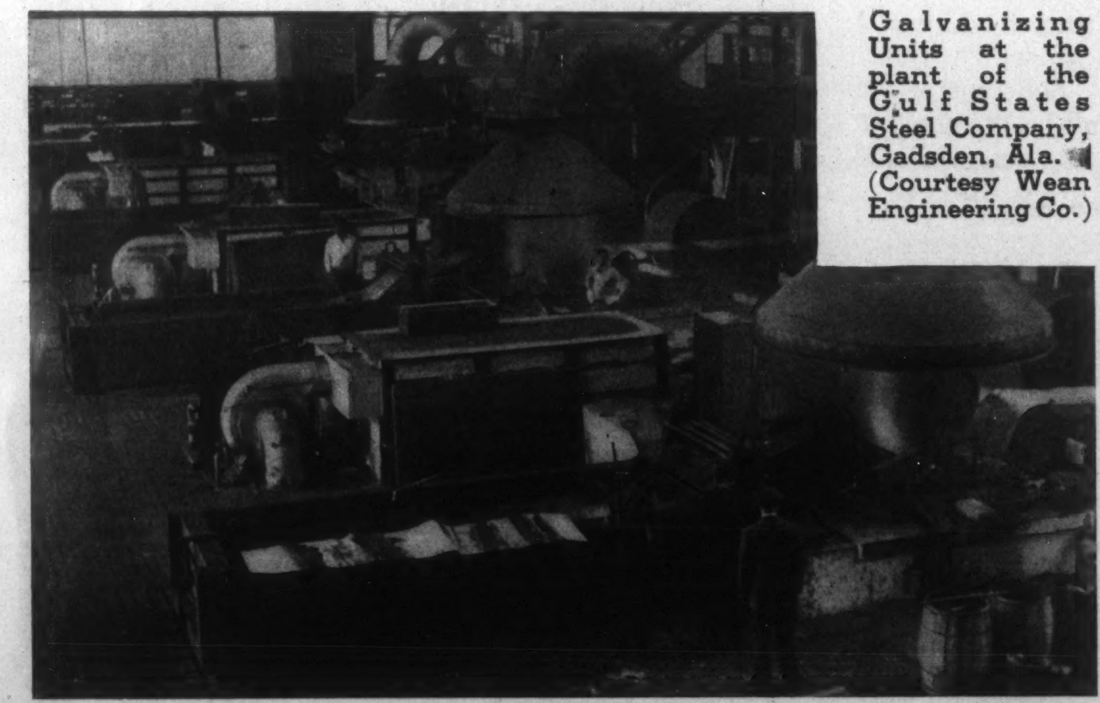
Sheet Galvanizing Machines Provided with Hoods for Carrying Off Fumes. (Courtesy United Engineering and Foundry Company.)

and phosphorus in the base material having an effect on the adherence of zinc coatings, it is very possible that they influence in some way the character of iron-zinc alloys formed.

The effect on these properties of the other usual impurities in the base material such as sulphur, manganese, silicon and copper or of alloying agents, nickel, chromium, vanadium, cobalt, etc., has not been studied to any great extent.

ADHERENCE AFFECTED BY SUBSEQUENT HEATING OF GALVANIZED COATINGS

The adherence of galvanized coatings is sometimes affected by the growth of the alloy layer in the coating through heating after the galvanizing operation. The peeling of zinc coatings from galvanized sheet iron smoke pipes in the ordinary household furnace is familiar to many. This same type of peeling has been noticed in galvanized structural steel where, as soon as the angles or shapes leave the galvanizing pot, they have been stacked unquenched in such a manner that their cooling has been seriously delayed. This heating at the temperature well below the melting point of zinc causes a growth of the iron-zinc alloy with an attendant consumption of most of the zinc in the pure zinc layer and, for some reason not clearly understood at present, destroys the bond between the alloy layer and the layer of pure zinc that remains so that the latter peels from the surface in much the same way as paint films do from the surface of smooth, bright galvanized iron. Paradoxically, if the coating is heated at a temperature above the melting point for a short time, as soon as the material leaves the galvanizing pot as in the case of the "galvannealing" process, all of the fluid zinc will be converted to gray colored iron-zinc alloy, no thin layer of zinc remains to peel away from the surface and a coating with good adherence is obtained.



Galvanizing Units at the plant of the Gulf States Steel Company, Gadsden, Ala. (Courtesy Wean Engineering Co.)

CORROSION OF DEFORMED ZINC COATINGS

Since the real purpose of zinc coatings is to protect the base metal from corrosion, the important question to be answered from a practical standpoint is not how much or how little the coating cracks but how well the coating protects the base metal after it has been deformed. It is obvious that coatings which flake or peel away from the base offer no protection against its corrosion. On the other hand visible cracks in deformed coatings do not necessarily imply the rapid destruction of the base at this point. The question of how much protection zinc affords bare, exposed iron through its well-known electro-chemical characteristics is one which has been investigated by a number of authorities. It is the general consensus of opinion that zinc protects the base only over a very limited area. However, even where the zinc coating fails with large cracks, the area of the base metal exposed is very small and undoubtedly the zinc in the adjacent coating gives considerable protection. Whether this protection is electro-chemical or results from the filling up and sealing of the crack with innocuous zinc salts is still an unsettled question. There is strong evidence for believing, however, that the latter mechanism of protection plays a very important part in preventing the rapid rusting of exposed base metal particularly in salt atmospheres. A study of the atmospheric corrosion of deformed zinc coatings made by several investigators shows that the heavier zinc coatings, even though they are badly cracked in forming as long as they do not peel, afford better protection to the base than the thin so-called "tight" zinc coatings which show no visible cracks after fabrication.

Cooling Wheels at Weirton Steel Company. (Courtesy United Engineering and Foundry Company.) These wheels are driven from the roller levelers by silent chains.

CONSUMER DEMANDS FORCING DEVELOPMENT OF GALVANIZING PROCESS

The greater attention given to the corrosion problem to-day by consumers has awakened an interest in better protective coatings of all sorts on the part of both the producer and consumer. In the particular field of galvanized products the use of heavier zinc coatings has been advocated by many large consumers of these products. At the same time there is a growing demand that is becoming more insistent every year for more ductile zinc coatings which will permit the use of heavier coatings on sheet and wire products that must withstand severe fabrication operations. These demands find their expression in more rigid specifications for zinc coated articles and such specifications are becoming more widely used every year by the consuming interests. The producer of these galvanized products finds himself in a difficult position in attempting to satisfy the demand for heavier and more uniform coatings on one hand and a demand just as insistent for ductile and more adherent zinc coatings on the other. The very nature of the zinc coating makes the solution of this problem a most difficult one. The two most outstanding recent developments in the art of galvanizing, the Crapo process for galvanizing wire and the so-called "galvannealing" process for wire and sheets, have both come about through an effort to solve this problem. However, these new processes are at present used in coating only a relatively small part of the total tonnage and the general improvement in the malleability of the great bulk of galvanized products, particularly sheets, is still to be made,

Future development of the galvanizing industry should be along the lines of the production of heavier and more uniform zinc coatings having better ductility and adherence in order to meet the increasingly more rigid and discriminating demands of the consumer as well as the keen competition now offered by the non-metallic roofing materials. Should advances of this kind be too long delayed, the past well established outlets for galvanized sheet and wire products, which already show signs of weakening, will be seriously restricted if not lost altogether.

REFERENCES

[1] Crapo. U. S. Patent No. 1,501,887 and subsequent patents.

[2] Herman. U. S. Patent No. 1,430,648–1,430,651 inclusive and subsequent patents.

[3] H. Bablik. Bending Conditions of Galvanizing. *Iron Age*, Vol. 125, May 1930, pages 1462–1463; 1528–1531.

[4] H. S. Rawdon. Structure of Commercial Zinc Coatings. *Proceedings American Society for Testing Materials*, Vol. 18, Part 1, 1918, page 216.

W. H. & A. W. Walker. Structure of Galvanized Iron. *American Institute of Metals*, Vol. 6, 1912, page 82.

W. Guertler. Structure of Galvanized Iron. *Zeitschrift für Metallographie*, Vol. 1, 1911, pages 353–375.

W. H. Finkeldey. Microstructure of Zinc Coatings. *Proceedings American Society for Testing Materials*, Vol. 26, Part II, 1926, pages 304–315.

[5] A. von Vegesack. The Alloys of Zinc and Thallium and of Zinc and Iron. *Zeitschrift für anorganische Chemie*, Vol. 52, Jan. 3, 1907, pages 30–40.

V. Raydt & G. Tammann. The Structure and Properties of Zinc-Iron Alloys Molten under Pressure. *Zeitschrift für anorganische Chemie*, Vol. 83, Nov. 4, 1913, pages 257–266.

W. M. Peirce. Studies on the Constitution of Binary Zinc Base Alloys. *Transactions American Institute Mining & Metallurgical Engineers*, Vol. 68, 1922, pages 767–795.

[6] H. Bablik. The Influence of Cadmium in a Galvanizing Bath. *Metal Industry*, London, Vol. 37, Oct. 31, 1930, pages 411–413.

[7] Wehr & Mahlie. U. S. Patent No. 1,788,755.

Finkbone. U. S. Patent No. 1,789,172.

◆ ◆ ◆ ◆ ◆

Editorial Comment continued from page 252

Notched-Bar Tests

It was not so long ago that notched-bar impact tests were looked upon as of purely academic interest. Some war-time makers of aircraft crankshafts even thought that low-impact shafts had at least as good a record as high-impact shafts, though a crankshaft would hardly seem to be a part in which impact would play a very direct role in service. The general expression was that "the notched-bar test shows what happens in a notched-bar test," and nothing more.

There have, however, been some strong adherents of notched-bar testing, notably Hoyt in this country, and Aitchison in England, and the general present trend seems to be toward their point of view.

We recall a talk by J. B. Johnson, of Wright Field, in which he showed slides of airplane landing gear parts which persisted in failing until material and treatment were used that gave high impact values, when the difficulty disappeared.

Although endurance tests do not themselves indicate it, notch-toughness seems to be needed in materials for severe service under repeated stress. No quantitative formula is known by which notched-bar figures can be tied in with endurance, but for many types of service, it is certainly advisable to sacrifice something in respect to the endurance limit as determined in the laboratory, in order to gain something in toughness.

It is true that the use of notched-bar specimens of different widths and depths, and with different notches will sometimes place two materials in a different order, and it may be necessary to use two sizes of bar to get a sufficient picture. Yet when such cases occur, they cause confusion only when the engineer brings his eye too close to them, and tries to deduce too detailed conclusions. If he is chiefly guided by the general order of magnitude of the values, he gets pretty reliable and useful information.

It is sometimes cited against the notched-bar test that it may, as it generally does in the case of low-temperature tests, reveal brittleness of notched specimens that is not marked if there is no notch present, but this is really a virtue. As long as engineers persist in using that abortion, the ordinary type of key-way, and forget what they know about the effect of sharp corners and poor fillets, it is worth while to have a test that will indicate something about the ability of material to withstand that sort of abuse.

It is widely bewailed that the figures for Izod and Charpy bars, and for each in different sizes and with different notches, cannot be accurately converted over into some uniform pounds-per-square-inch basis. Some degree of standardization would be desirable, but after all, perhaps the situation is somewhat of a blessing in disguise because it tends toward the use of the data more for the placing of a group of materials in some relative order than for the drawing of too fine haired distinctions.

If one is shy on material, he can get more check tests by using the Izod. If he wants to study high- or low-temperature brittleness, the Charpy is far more convenient. With a given type and size of bar, the use of different notches often throws light on the properties of the material, and different sizes of bar are naturally required in testing such extremes as cast iron and Monel metal.

The case for repeated-impact notched-bar tests seems less well proven, though some metallurgists put considerable reliance upon them. They might be more popular around the laboratory if they didn't involve such a nerve-racking noise.

The tendency toward including impact tests in any general survey of the properties of alloys is to be commended. The test is rapid and cheap, and it does give information that is useful if it is interpreted with the aid of considerable common-sense.—H. W. GILLETT

Editorial Comment continued on page 276

ATOMIC HYDROGEN

BY J. T.

THE atomic hydrogen process of welding was developed several years ago in the research laboratory of the General Electric Company. Working on an entirely unrelated problem, an engineer discovered that the passing of hydrogen through an electric arc intensified its affinity for other elements, particularly oxygen. Hydrogen, as commonly furnished for commercial purposes, is in the molecular state. Each molecule is composed of two atoms. In passing through the intense heat of the electric arc these atoms are separated and are in an unstable and extremely active state. Either a reunion to form molecular hydrogen or a union with another element to form a stable combination will occur at the first opportunity. Encouragement in this combination is furnished by contact with a relatively cold surface. Such characteristics suggested the possibility of developing a welding process, as the energy imparted to the gas by the arc would be released by contact with the parts to be welded and the reducing action of the gas would assist in purifying the weld metal.

A SCIENTIFIC phenomenon is always interesting, at least to scientists, but it is not very valuable till somebody puts it to work.

Putting it to work requires a thorough knowledge of the scientific principles involved, suitable facilities, much patience, the will to accomplish and besides all that, a special brand of engineering ability.

The General Electric Company is outstanding in its ability to translate the findings of its research staff into improved products or better ways of making old ones.

Welding with atomic hydrogen, described in this article, is a translation of "high-brow" physics into everyday shop practice.

A description of Fig. 1, which is a purely hypothetical apparatus, will assist in visualizing this. Two electrodes project inwardly through the walls of a tube in a position which would cause them to intersect at an angle of about 60°. The tube is of a heat resisting material of sufficient translucency to allow a clear view of the arc although impervious to the ultra-violet light which is dangerous to the eyes. Current flows through the electrodes, causing an arc to form at their converging ends. Hydrogen flows through the tube and that which passes through the arc stream is converted into atomic hydrogen. The well defined portion of the arc, much like that of a horse shoe in shape, is the zone of concentrated atomic hydrogen. Its size is dependent on the intensity of the current and the gap between the electrodes. A 50-ampere, 100-volt arc is about the diameter and thickness of a dime, its temperature is above 4000° C. and the energy imparted by it to the hydrogen is 5 kilowatts. The atomic hydrogen recombines readily after leaving this zone, although of sufficient concentration to melt tungsten wire an inch or more from the fringe of the arc.

Obviously, considerable modification is necessary before the above apparatus can be used as a welding tool. The perfected electrode holder is illustrated in Fig. 2. Two jets of hydrogen, each surrounding one of the electrodes, replace the tube. The result is two streams of hydrogen which unite at the junction of the electrodes, surrounded by a burning envelope. A handle and a means for varying the gap between the electrodes and compensating for consumption of electrodes, have been added. Current and hydrogen are introduced into two insulated tubes which carry the current to the electrodes and the hydrogen to the jets or tips. As the electrodes are consumed they may be adjusted in their respective clamps. A trigger provides

---

* General Electric Company, Schenectady, N. Y.

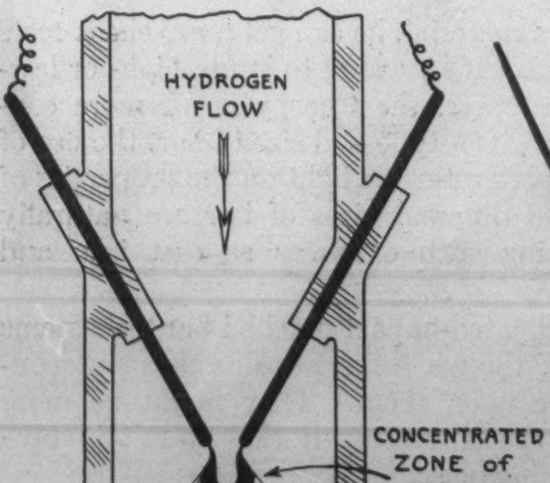


Fig. 1. Sketch showing method for producing atomic hydrogen.

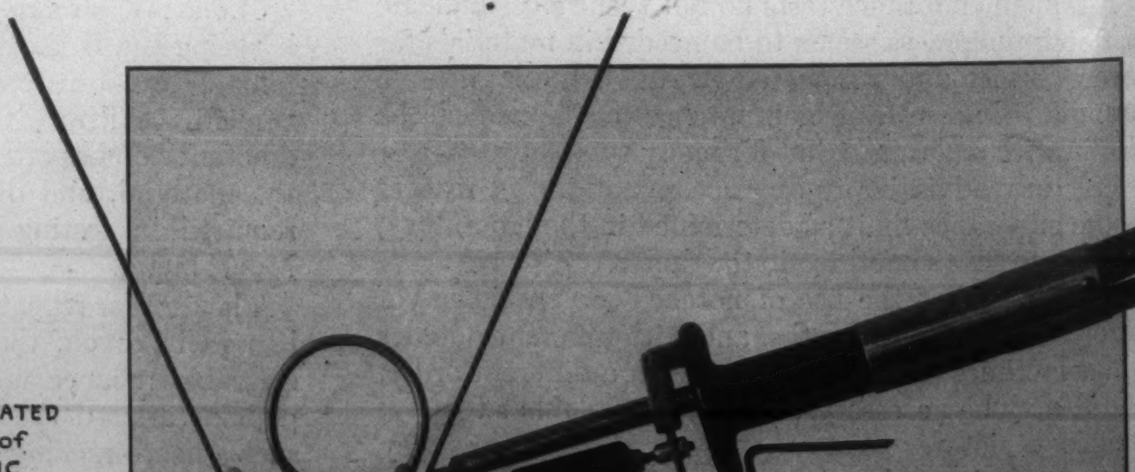


Fig. 2. Atomic Hydrogen Electrode Holder.

ARC WELDING

CATLETT*

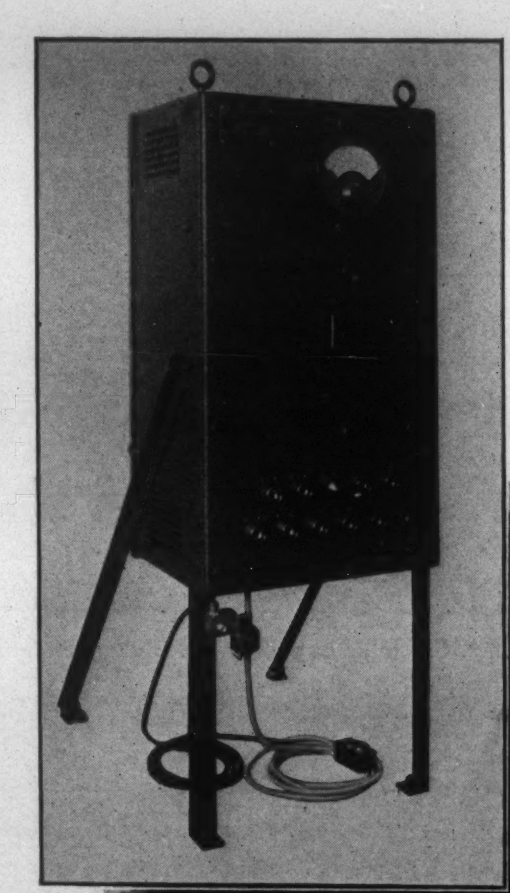
movement of one electrode with respect to the other for striking the arc and for adjusting the arc length.

In order to furnish the varying degrees of heat required for the many welding applications, the current is varied through a wide range. Alternating current being more universal and having the advantage of equalizing electrode consumption, is used in preference to direct current, although it is possible to use the latter. The equipment for controlling the current is shown in Fig. 3. It consists principally of a panel on which are mounted a variable reactor and the necessary contactors and relays for proper control. Changes in current are obtained by inserting a plug in different sockets.

Differing from other arc welding processes, the electrical circuit in the atomic hydrogen process does not include the work. The arc is established between the electrodes before beginning to weld. The fringe of the fan shaped flame is applied to the parts to be welded. The heat released by recombination fuses the parts together in a bath of hydrogen. Oxides, if present are reduced. The resulting weld is strong, ductile, and remarkably free from porosity. If desired, additional metal in the form of filler wire may be fused into the weld to increase the strength or to allow subsequent grinding.

Many unusual welds, though not always of a practical nor commercial nature, have been made by this process. Pure zinc has been welded. Precious metals, such as platinum and iridium, have been fused without danger of oxidation. Tungsten rods have been welded together although the weld is necessarily brittle because of the nature of the metal. Fused quartz may be reduced to a molten state. The welding of lead, more commonly called lead burning, is easily accomplished.

Continued on page 276



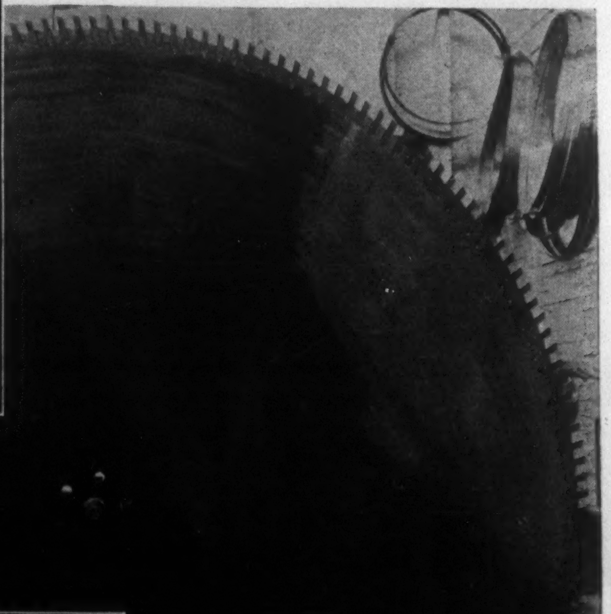


Fig. 3. Atomic Hydrogen Power Control Equipment.

Fig. 4. Saw in Fig. 5 after repair was completed.

Fig. 5. 108 Inch circular steel saw in process of repair.

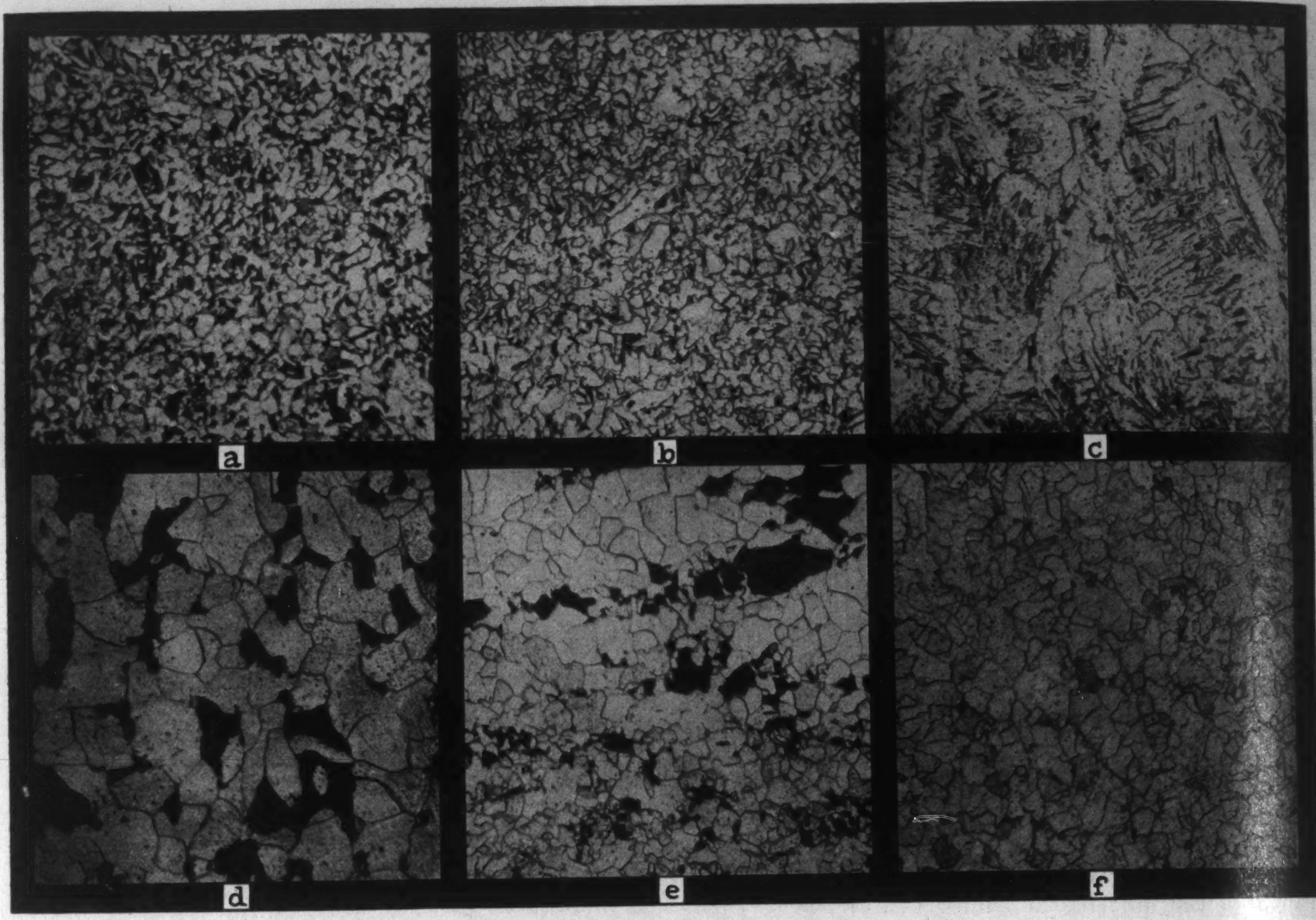


Fig. 6. (See captions on facing page.)

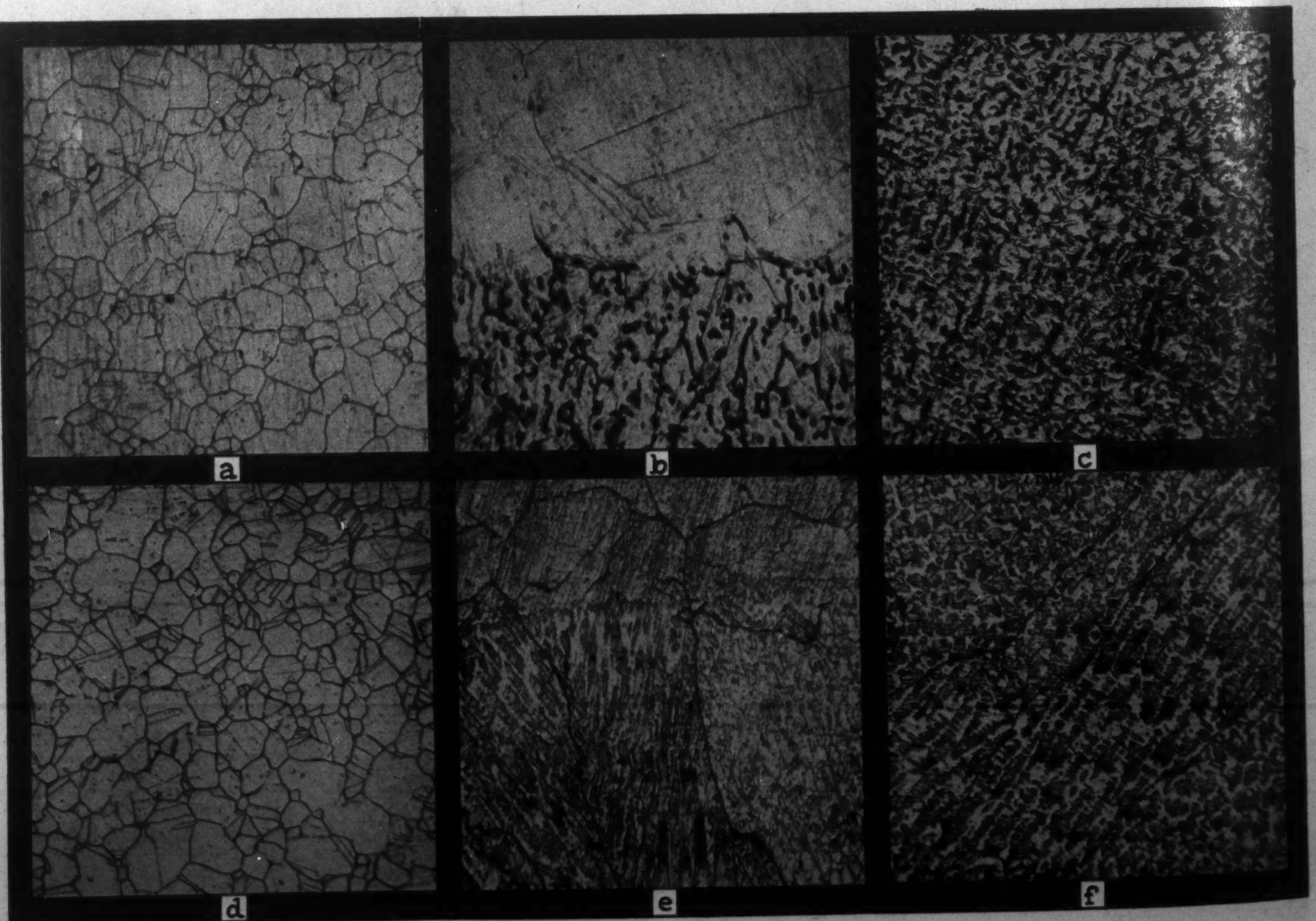


Fig. 7. (See captions on facing page.)

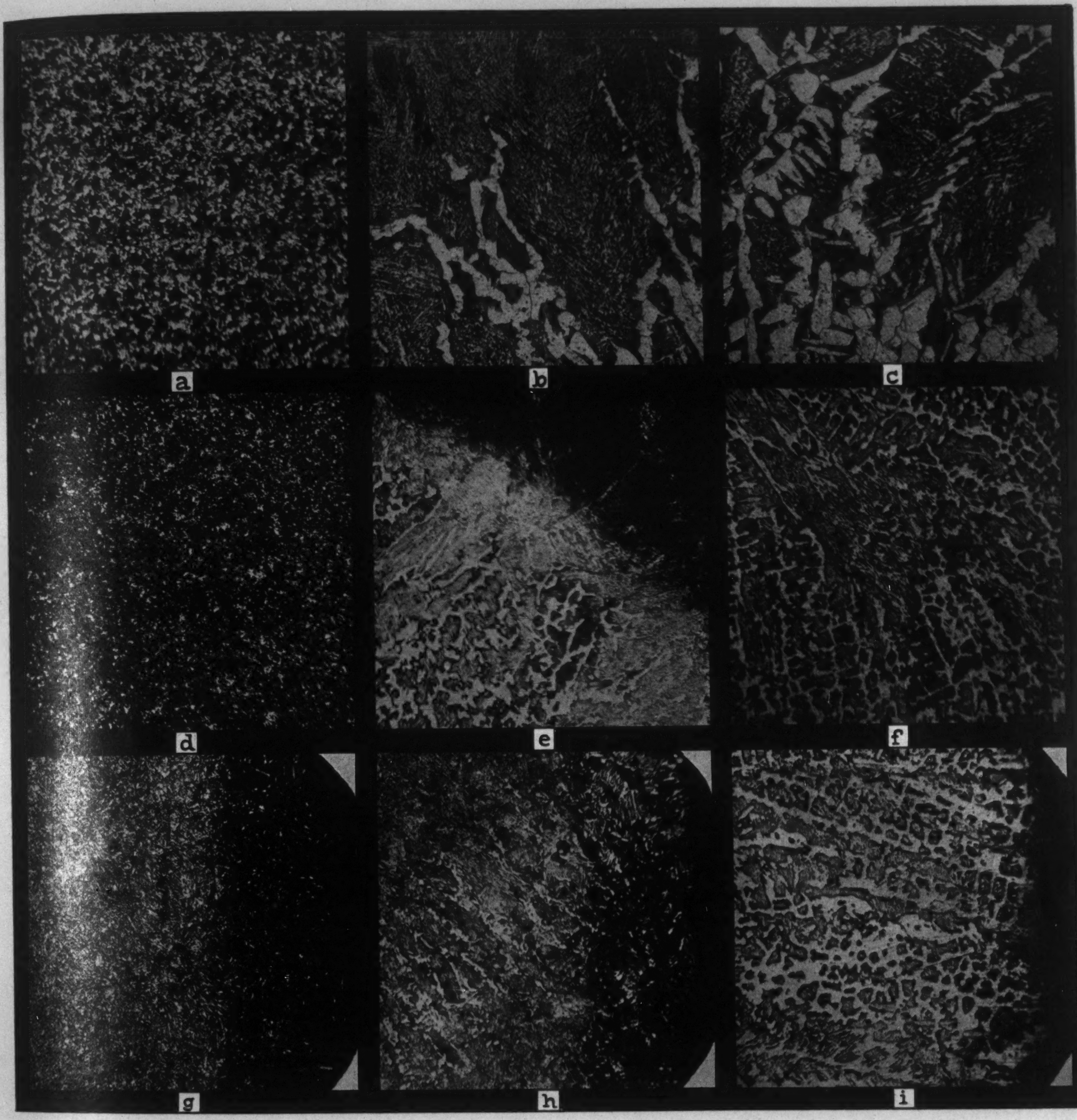


Fig 8.

Fig. 6. Photomicrographs of low carbon steel (approx. SAE 1020) welded by the Atomic Hydrogen process. Heat treatment consisted of annealing at 900° C. Mag. 100×. a. Base metal as welded. b. Fusion zone as welded. c. Weld zone as welded. d. Base metal after heat treatment. e. Fusion zone after heat treatment. f. Weld zone after heat treatment.

Fig. 7. Photomicrographs of a high chromium-high nickel stainless steel (18% Cr, 8% Ni) welded by the Atomic Hydrogen process. Heat treatment consisted of heating to 950°C. for 1 hour and quenching in oil. Mag. 100×. a. Base metal as welded. b. Fusion zone as welded. c. Weld zone as welded. d. Base metal after heat treatment. e. Fusion zone after heat treatment. f. Weld zone after heat treatment.

Fig. 8. Photomicrographs of Nitralloy G welded by the Atomic Hydrogen process. Material of the same analysis as the base metal was added to fill in a "V" groove approx. $^{3}/_{8}$" deep and $^{3}/_{4}$" wide at the top. Heat treatment consisted of heating to 950° C., quenching in oil and drawing to 600° C. Nitriding was done after heat treatment. Mag. 100×. a. Base metal as welded. b. Fusion zone as welded. c. Weld zone as welded. d. Base metal after heat treatment but before nitriding. e. Fusion zone after heat treatment but before nitriding. f. Weld zone after heat treatment but before nitriding. g. Base metal after nitriding. Dark section shows depth of nitriding. h. Fusion zone after nitriding. Dark section shows depth of nitriding. i. Weld zone after nitriding. Dark section shows depth of nitriding.

Turning to the more practical applications, the majority of installations are for the welding of light gage steel, that is 12 gage to 20 gage. The principal reason for its use here is the appearance of the weld, although the high welding speed obtained is also a factor. For the majority of products the weld is sufficiently smooth without grinding or finishing. Enamel can be applied over the weld with no more preparation than that given the unwelded portion.

In direct contrast, considerable welding is being done on very heavy material. Large steel castings are being salvaged by using this process to repair flaws. The structure and strength of the repair are practically the same as the casting itself and the appearance is such that only a careful inspection reveals the repair. Fabrication from heavy steel plate where strength and ductility are paramount is also common. A striking example of the welding of heavy material is furnished in Figs. 4 and 5. A large steel saw, broken in service was successfully reclaimed by welding in a section to replace the part broken out.

Alloys and non-ferrous metals are readily welded. Chief among these is that group of high chromium steels more generally classified as stainless steels. The weld, however, is generally more brittle than the parent metal, but is susceptible to heat treatment. Aluminum, brass and monel metal are other materials finding frequent application.

Nitriding steels have been finding frequent applications recently, particularly in tool and die manufacture. Errors in machining may be corrected by building up the section with material of the same analysis. After the proper heat treatment the piece is properly machined and nitrided. Although the depth of the nitriding usually is not quite as great as in the base metal, the hardness is comparatively the same.

In all types of fusion welding there generally is produced three distinct metallurgical structures. The cause is very apparent when the mechanics of the weld are considered. The weld zone is raised to a temperature very close to, if not actually above, the melting point. The temperature of the base metal, at some distance from the weld, has not changed to any marked degree. In between these extremes is a zone which has been raised to a sufficient temperature to change the structure particularly in regard to grain size.

In some welds these zones are clearly defined while in others the change in structure from the base metal to the weld is very gradual. The clearness with which the zones are defined depends to some extent on the process but to a greater extent on the kind of material, its mass and the speed of welding. Subsequent heat treatment tends to change the structure of the weld and fusion zones to that of the base metal. The accompanying photomicrographs are, in all cases, views of these three zones.

◆ ◆ ◆ ◆ ◆

Editorial Comment continued from page 271

The Technical Parasite

Parasites are found in all walks of life and in all phases of human activity. They are as conspicuous in the technical world as elsewhere. The technical parasite is generally in the employ of a large manufacturing concern. He attends the meetings of scientific and technical societies and even condescends to serve (?) on technical committees. While papers are being read or discussed he generally remains silent, seldom responding to an invitation to contribute to the discussion, more rarely still volunteering any information. His food consists chiefly of the crops laboriously raised by others and of this he partakes copiously and, if perchance he succeeds in raising a little himself, he guards it for his own consumption. Notwithstanding this parasitic feeding, his attitude instead of being one of humility and thankfulness is often critical, not to say arrogant.

As a member of technical committees his work is generally destructive. It is obvious that his interest in the labor of the committee ends when, in his judgment, it ceases to benefit him. He is secretive as to whatever information he has or fancies to have. While eager to receive, he is ever reluctant to give. He would even prevent the dissemination of knowledge likely to benefit others as it benefits him. He frequently affects to be the wise possessor of knowledge not available to the other members. This little game flatters his vanity.

What is there to be said in defense of the technical parasite? Certainly his vision is limited to the monetary value of his technical knowledge. He is unable to grasp the greater meaning, greater duty and greater reward attached to a more lofty conception of the services owed by engineers to their fellow men. He apparently believes that he is serving the best interests of his employers—that his parasitic habits make him a more valuable man. In this egotistical attitude is he not misguided, even from a purely sordid point of view?

There are those who believe that a freer and more generous interchange of thoughts and information among technical men commercially engaged would promote progress in a way that must necessarily prove of much benefit to all. It is far from demonstrated that modern business, to be successfully conducted, is dependent on Chinese walls erected and guarded by technical parasites. It is now quite generally admitted that honesty is the best policy, in spite of the immediate returns which are seemingly within reach of the dishonestly inclined. Let us hope that the time will also come when the policy of free interchange of thought and knowledge will be recognized as the best policy by those sordidly inclined, in spite of the apparent gains to be derived from a parasitic policy.

Personally the technical parasite may be a very good fellow, but as a member of the great industrial, technical fraternity, he is worse than useless.—ALBERT SAUVEUR

Back-Bone

There are always some applications for which a material is wholly unsuited, and for which even the most eager salesman or advertiser would not claim adaptability. There are others for which a given type of material is admittedly and preëminently suited. These extremes offer no marketing problems. But among competitive materials, a situation often arises in which, any one of half a dozen alloys for example, may seem at the outset to offer equal service per dollar of cost. No one can blame those engaged in the production of each of the half dozen for singing its praises, and trying to get it adopted for that service.

Time goes on, and service successes and failures come to light. Exhaustive laboratory studies are made to duplicate service conditions, and real information is amassed. It's not a public race, but a private time trial, in which the half-way post looks like a dead heat among all entries, but at the finish, the horses are pretty much strung out. Only the jockeys know the results. The average purchaser doesn't known which alloy is the best, but the metallurgists of the producers do know.

In a perfectly proper effort to get their material tried out in the race, the sales and advertising forces of all six producers have spent much money and effort. Each one may have a nice slogan that implies the superiority of their alloy for this service.

What is the metallurgist going to do when he knows his company's product is not the leader in the race, and his research shows no reasonable prospect of its being made so? The sales force may want to go ahead and sell just as long as sales can be made, whether or not the customer is getting the most for his dollar. The shop is used to handling the material that is not the best for the purpose, and so the production staff doesn't want to change to the better alloy. Perhaps the material that is really best is so hedged about by patent restrictions, real or alleged, that it is not feasible to change to it.

As sure as God made little apples, the customers will find out the facts some day, and switch to the material that is truly the best engineering choice for the purpose. But they can be hood-winked and stalled off for a while.

A somewhat similar situation arises when a lot of service and test data are available which show, if impartially considered, that the competing materials are still running neck and neck, but which, by shrewd selection of data and the suppression of the unfavorable results, can be made to lead the customer to conclude that one is really measurably better. Or, by choosing a particular type of test that sounds impressive to the layman but doesn't really evaluate the properties utilized in service, an impressive false front can be built up.

What is the metallurgist going to do when he is asked by the sales and advertising groups of his company for more technical ammunition for sales-promotion of the losing material? Shall he take the apparently easiest way, handpick his data, and serve up that which will make a good showing, or shall he advise that sales pressure for that one of the firm's products be held off until research has developed something that he can honestly advocate as at least as good a buy for the customer as the competitor's product?

Company pride and the hope of continuing to make a profit on a line that can still be sold by high-pressure salesmanship, though not on its merits, may make the sales force look upon the metallurgist, who will not stultify himself, as a mutineer.

The metallurgist is often in a position to see the handwriting on the wall as to what sort of product will ultimately win out, far earlier than the sales force will see it in decreased orders.

Is he not short-sighted if he does not urge the management to trim its sails, and "stand by to come about?"

Executives these days know that the only certain thing is that change will take place. Instead of being a mutineer, the technical man who senses that the firm is on a dangerous course, is the really loyal member of the crew when he warns of the rocks ahead.

Back-bone enough to stand out against those who want to make temporary profits by high-pressure salesmanship instead of building up a permanent market on the true merits of a commodity, is usually appreciated by the executive. If it isn't appreciated, that executive's ship is headed for a wreck sooner or later, and the metallurgist might as well enter the crew of some other ship that is steered by executives of a higher type.—

H. W. Gillett

◆ ◆ ◆

Soft Solders and Their Application by G. O. Hiers

References continued from page 261

[33] E. Schumacher & E. J. Basch. Lead-Tin-Cadmium as a Substitute for Lead-Tin Wiping Solder. *Industrial & Engineering Chemistry*, Vol. 21, 1929, page 16.

[34] W. E. Goodrich. Volume Changes during Solidification of Solders. *Transactions Faraday Society*, Vol. 25, 1929, pages 543–546.

[35] J. Silberstein. A New Solder for Electrical Apparatus. *Metals & Alloys*, Vol. 1, 1930, pages 659–660.

[36] Standard Specifications for Solder Metal, No. B 32-21, *A. S. T. M. Standards*, Part I, Metals, 1930, pages 695–698.

[37] S. J. Nightingale. The Jointing of Metals, Part I, Soft Solders and Soldered Joints. *Research Reports, British Non-Ferrous Metals Research Association*, No. C 234-214, Dec. 1929, 96 pages.

[38] Nobutoshi Aoki & Shojiro Waki. An Investigation of Type Metals, Part 4. On the Equilibrium Diagram of the Lead–Antimony–Tin System. *Naikaku Insatsu-kyoku Kenkyojo Chosa Hokoku* (The Report of the Research Laboratory, Government Printing Bureau, Japan), No. 21, Nov. 1930, pages 1–36.

[39] J. G. Thompson. Properties of Lead-Bismuth, Lead-Tin, Type Metal and Fusible Alloys. *Bureau of Standards Journal of Research*, Paper No. 248, Vol. 5, 1930, pages 1091–1093.

[40] K. Hilding Beij. Seams for Copper Roofing. *Bureau of Standards Journal of Research*, Paper No. 216, Vol. 5, 1930, pages 585–608.

[41] K. Steiner. The Use of Soft Solder at High Temperatures. *Metallwirtschaft*, Vol. 9, 1930, pages 502–503.

[42] A. Eyles. Solders and Soldering Fluxes. *Sheet Metal Worker*, Vol. 21, 1930, pages 600–608, 668–672, 688–708.

[43] Wm. Mason. Modern Solders and Their Applications. *Chemical Engineering & Mining Review*, Vol. 22, 1930, pages 189–190.

[44] C. J. Elliott. What Price Solder? *Industrial Engineering*, Vol. 88, 1930, pages 120–121.

[45] American Society for Steel Treating. *National Metals Handbook*, 1930, pages 725–727.

[46] A. Eyles. Repairing Pewter. *Brass World*, Vol. 27, 1931, pages 27–28.

[47] U. Magnani & C. Panseri. The Joining of Aluminum and Its Alloys. *La Metallurgia Italiana*, Vol. 23, 1931, pages 85–101.

◆ ◆ ◆

The Electric Furnace Company, Salem, Ohio designers and builders of electric-, oil- and gas-fired industrial furnaces announce the appointment of Mr. Ray G. White as eastern sales representative.

Mr. White was formerly with the Mahr Mfg. Company, and has had over ten years' experience in the industrial furnace field. He will have charge of both electric and fuel furnace sales in Northeastern Pennsylvania, Eastern New York and the New England States, with headquarters at 55 West 42nd St., New York City.

SILVER SOLDERS

BY R. H.

AT THE present price of silver, it is reasonable to expect that soldering jobs in which a really strong joint, or one that will stand rather high temperatures, is needed, will utilize silver solders in in-

INDISCRIMINATE use of the terms welded, brazed and soldered as applied to joining metals prevents anyone from forming a definite conception of the particular method which has been used unless additional information is available.

Before the development of electric welding, oxy-hydrogen or oxy-acetylene torches, the term welding ordinarily meant that mechanical force as well as heat was used in making the joint. Brazing usually referred to joints made with brass or spelter. Soldering probably brought to the minds of most of us the use of a low melting tin-lead alloy, although the term hard solder was used to define those alloys which required a temperature above a dull red to melt them.

Regardless of the particular name given to the method of joining metals or the procedure followed in making the joints, the adhesion must be sufficient to give the required strength. The degree to which actual diffusion takes place and the effect of this diffusion on the strength of the joint would seem to be worthy of investigation. Assuming that other factors are constant it is generally accepted that diffusion of metals and alloys is dependent upon time and temperature. When one considers that even in the case of hard solders their melting points are usually well below the fusion point of the metals to be joined and the time during which the solder is liquid is relatively brief, one would not expect the diffusion to be extensive and it might be only of molecular proportion.

In order to study the characteristics of the bond between silver solders and various metals a large number of specimens were made at the Research Laboratory of Handy & Harman and micrographs were taken at magnifications running from 100 to 1000. The difference in hardness between the solder and the metals in many cases makes it difficult to obtain a polished surface for microscopic examination that is perfectly flat. This uneven surface is more pronounced at the boundary between the solder and the metal which is the particular zone where diffusion would be most pronounced. In addition to the difficulties in polishing, there is the question of getting a reagent which will etch the specimen in such a manner as to

---

* Manager, Handy & Harman, Bridgeport, Conn.

Fig. 1A. Copper soldered with 20% Silver, 45% Copper, 30% Zinc, 5% Cd. Mag. 500×. Etched with $NH_4OH + H_2O_2$.

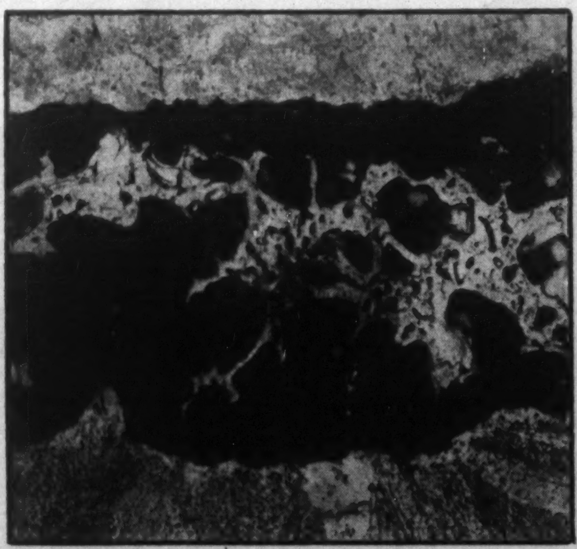
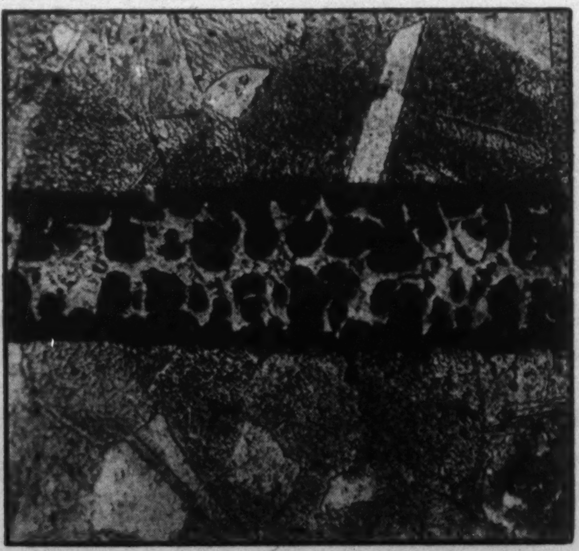


Fig. 1B. Copper soldered with 50% Silver, 34% Copper, 16% Zinc. Mag. 500×. Etched with $NH_4OH + H_2O_2$.



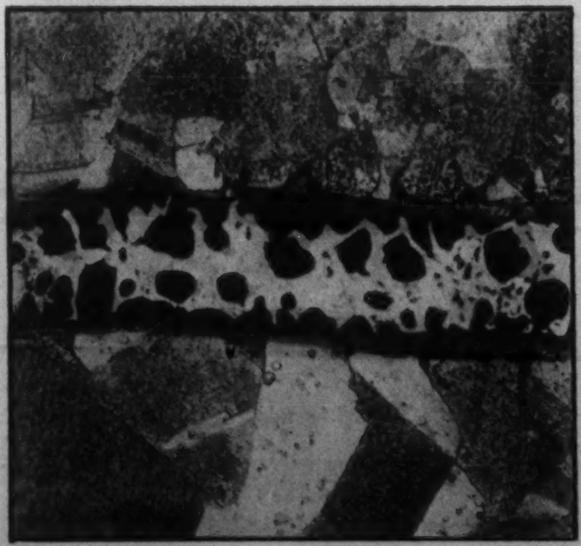


Fig. 1C. Copper soldered with 65% Silver, 20% Copper, 15% Zinc. Mag. 500×. Etched with $NH_4OH + H_2O_2$.

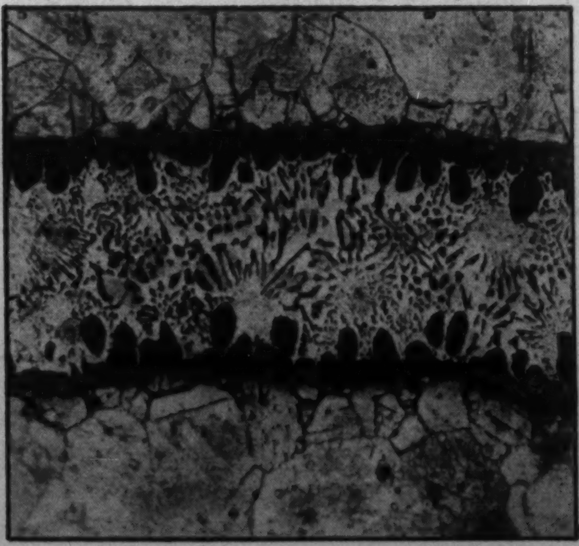
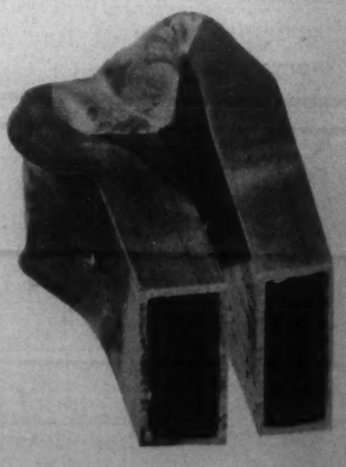


Fig. 1D. Copper soldered with 80% Silver, 16% Copper, 4% Zinc. Mag. 500×. Etched with $NH_4OH + H_2O_2$.



Rectangular hollow bronze section silver sol-

and Their USE

LEACH*

creasing degree. Hence, the various phenomena related to the use of silver solders, such as those described in this article, and the hints on their practical use, become of increasing interest.

allow a satisfactory study of the degree of diffusion. It is not intended in this article to give a comprehensive review of all of the work which was done, but the study of the specimens proved of great interest and some typical examples have been selected.

In general the investigation was conducted along two lines:

First—A large number of closely fitted silver soldered joints were made using different metals and alloys.

Second—A study was made of the amount of diffusion in specimens which were kept in contact with the molten solder for periods of 30 minutes to 2 hours.

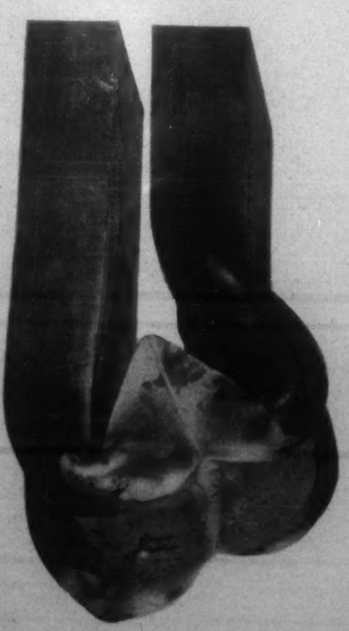
The first set of specimens illustrated in Fig. 1 were made from cold rolled copper strip, 14 gage × $^5/_8$" wide. Carefully fitted butt joints were made. The joints were heated with an oxy-acetylene torch to a temperature just above the liquidus of the solder, care being taken not to overheat the copper more than was necessary for the free flowing of the different solders. The joints were then polished and etched for microscopic examination.

Another series of joints is shown in Fig. 2. In this case, the same silver solder has been used, but the joints have been made with different metals. All of these micrographs were made at 500 diameters, because with closely fitted joints of this type the maximum space to be filled with the solder will seldom exceed 0.002" and it was desired to get sufficient magnification to determine even a slight degree of diffusion.

As would be expected there is considerable variation in the different micrographs. In each case, however, there is a very definite zone of diffusion.

Specimens for a further study of the diffusion of the silver solders were made as follows:

Holes $^1/_8$" in diameter and approximately $^3/_8$" deep were drilled in small blocks of the metal being investigated. This hole was filled with solder and covered with borax flux. The specimen was then put in a small electric muffle furnace and kept at temperatures ranging from a few degrees to several hundred degrees above the liquidus point of the particular silver solder which was



dered and then subjected to severe bending tests.

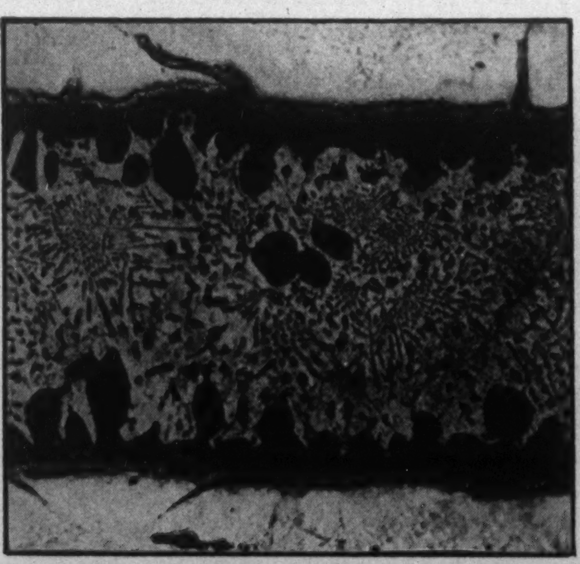


Fig. 2A. Brass soldered with 50% Silver, 34% Copper, 16% Zinc. Mag. 500×. Etched with $NH_4OH + H_2O_2$.

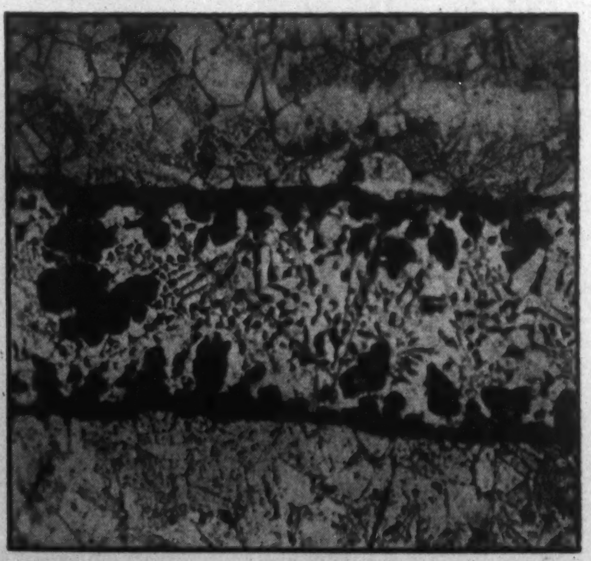


Fig. 2B. Nickel silver soldered with 50% Silver, 34% Copper, 16% Zinc. Mag. 500×. Etched with acid ferric chloride.

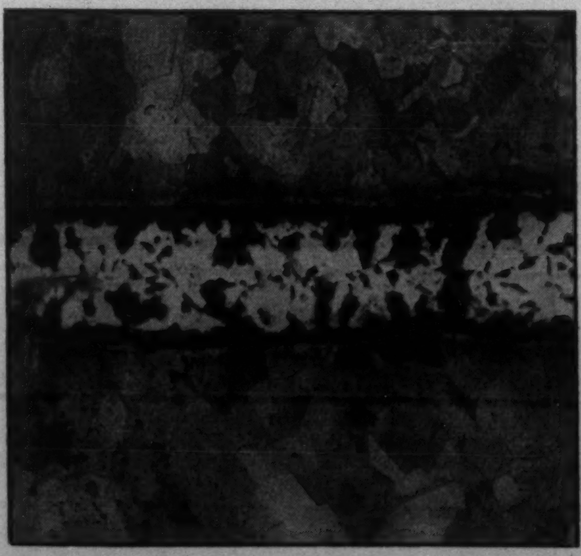


Fig. 2C. Nickel soldered with 50% Silver, 34% Copper, 16% Zinc. Mag. 500×. Electrolytic Etch.

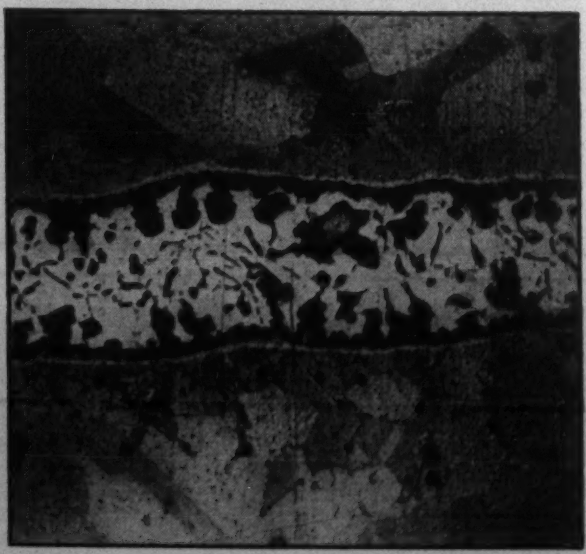


Fig. 2D. Monel metal soldered with 50% Silver, 34% Copper, 16% Zinc. Mag. 500×. Electrolytic Etch.

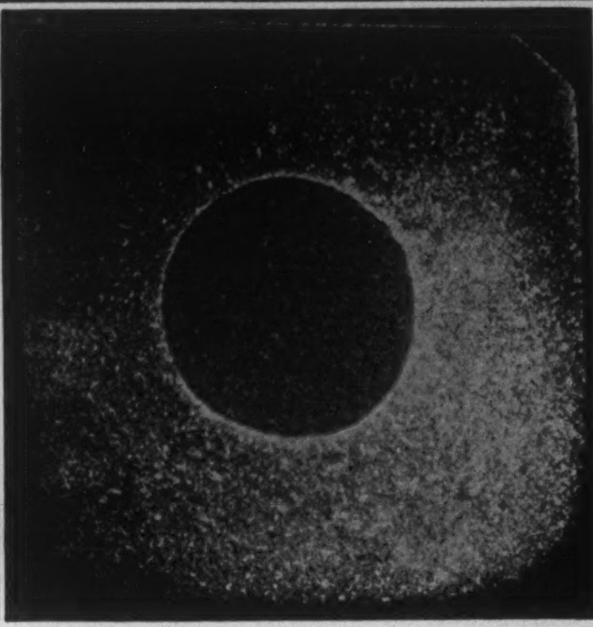


Fig. 3A. 65-35 Brass and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium ½ hr. at 1500° F. Mag. 7×.

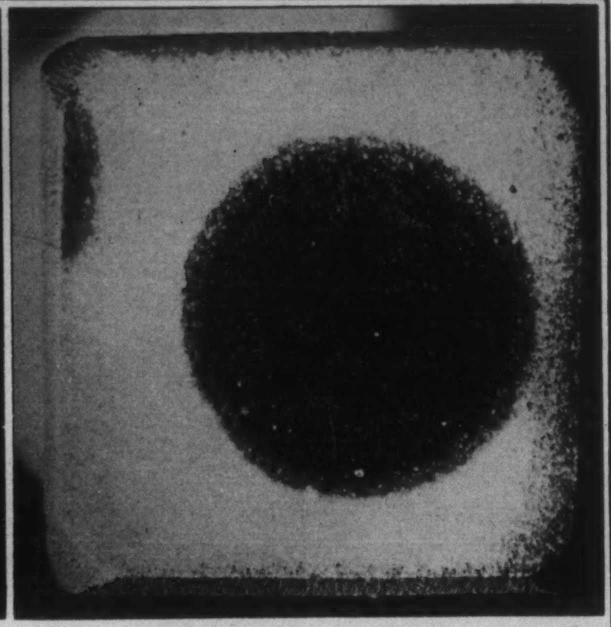


Fig. 3B. 65-35 Brass and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium ½ hr. at 1600° F. Mag. 7×.

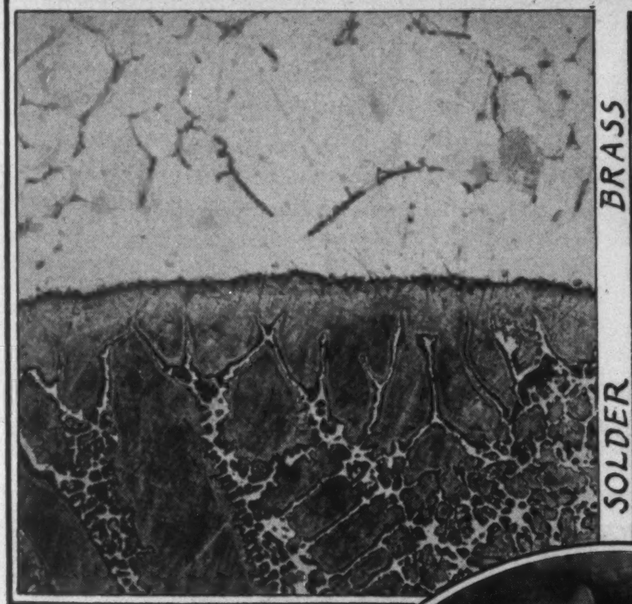


Fig. 3C. 63-35 Brass and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium ½ hr. at 1500° F. Mag. 100×.

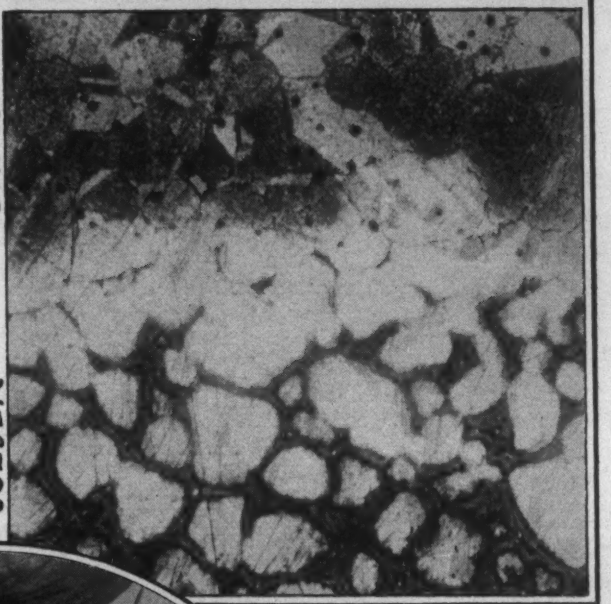


Fig. 3D. 65-35 Brass and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium ½ hr. at 1600° F. Mag. 100×.

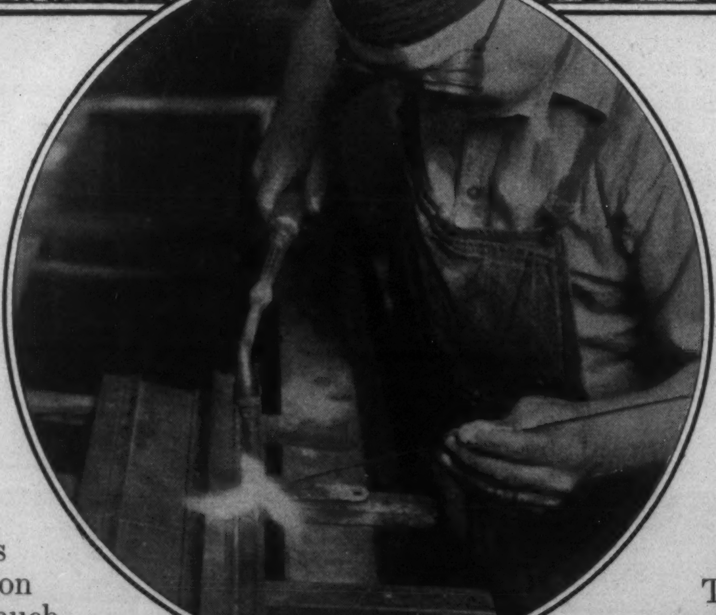
being tested. The upper part of the specimen was cut away to insure the removal of any oxidized portion and the surface polished for microscopic examination.

Fig. 3 shows the effect of heating for a period of one half hour at two different temperatures. The brass used in these specimens contains 65% copper and 35% zinc. The flow point or liquidus of the solder was 1500° F. and it is quite noticeable that the diffusion at the liquidus point is very much slower as compared with a temperature 100° above the liquidus.

Fig. 4 illustrates the difference in the rate of diffusion in copper and iron as compared with brass as shown in Fig. 3.

It is difficult to select a few random photomicrographs that will show all of the interesting points that were developed by an investigation of this kind. The microscopic examination of the specimens themselves under different magnifications allows a much better opportunity for comparative analysis, but the general conclusion from all of this work was to the effect that in all the specimens examined there was a definite zone where actual diffusion had taken place.

The actual penetration of the solder was slight, but was greatly increased by a small amount of super-heat above the liquidus of the solder. This point may have an important bearing upon the advantages of using silver solders with relatively low melting points even although the joints are made at temperatures considerably above the liquidus of the solder.



Joining wide section of extruded bronze.

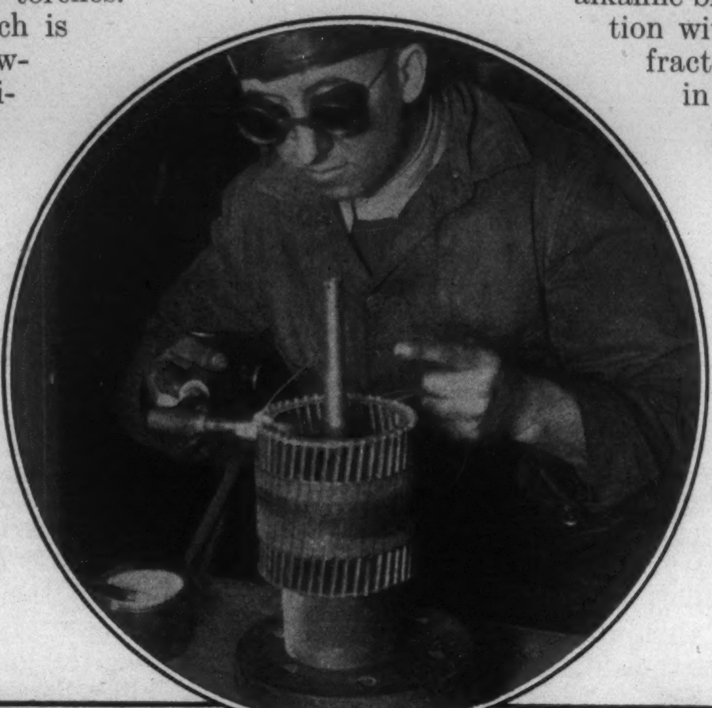
The Practical Use of Silver Solders

The following comments which are based upon a wide range of laboratory and field tests in connection with silver solders and brazing alloys, may be of interest.

The selection of the proper grade of solder is important. In many instances the first cost of the solder is given too much consideration. This attempt to economize may result in increased labor costs, defective joints or damaged parts, which will more than offset any saving made in the purchase price of the solder. The list of silver solders given in A. S. T. M. specification B73-28T covers the range which should meet the majority of industrial requirements. Where unusual conditions have to be met, it may be desirable to have special solders, but more attention to the correct use of these standard silver solders will eliminate the necessity for special alloys. Specifications alone, however, are not sufficient and the solder should be purchased from some reliable source, in order to insure having a product which has been properly manufactured and does not contain oxides and harmful impurities which will not be discovered under ordinary chemical analysis. The method of heating, the quantity and quality of flux and the provision of suitable equipment must be given attention in order to make good joints with efficiency and minimum cost.

The heating may be done in furnaces, electrical resistance devices or by torches. The most common form of torch is the gas and air. This torch, however, does not have the flexibility of the gas and oxygen or oxy-acetylene torch. The oxy-acetylene torch has the advantage of a wide range of temperature between different parts of the flame and also characteristics of the flame can be changed so that a reducing flame of high temperature can be maintained. The workman who is accustomed to the gas and air torch may have some difficulty with overheating with oxygen-gas or oxy-acetylene when he first attempts to use them, but he will soon acquire the necessary skill. When a torch is used for heating the joint, it is advisable to have the light conditions as constant as possible. When work benches are set at the windows the effects of cold drafts of air and varying light conditions during working hours or from sunny to cloudy days have a material effect and are often the cause of defective work.

The majority of fluxes for use with silver solder or brazing alloys have either borax, boric acid or a combination of these as their principal ingredients. The alkaline bifluorides are used in combination with borax or chlorides where refractory oxides, not readily soluble in borax, are likely to form. All parts of the joints should be well protected with flux. Bare spots which are not protected with flux during the preliminary heating are almost certain to become coated with films of oxide and the workman does not feel that he can take the time to put on more flux. Consequently the molten flux, although it may finally spread over these areas, does not have sufficient time to entirely dissolve these



Silver soldering on armature.

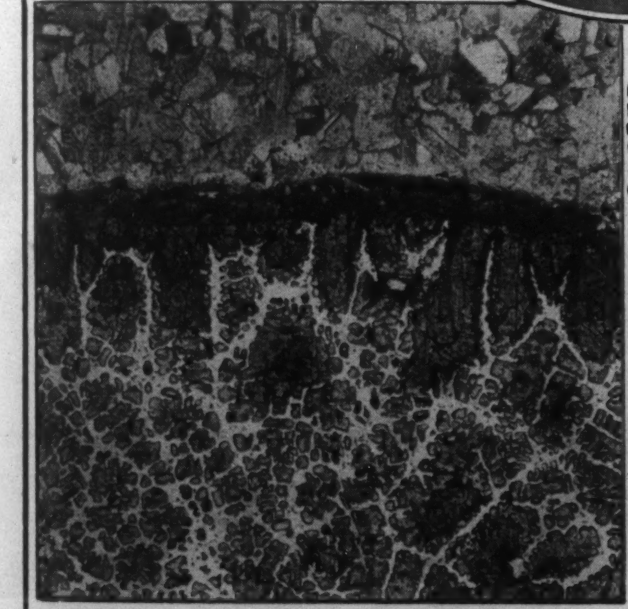


Fig. 4A. Copper and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium. 1/2 hr. at 1500° F. Mag. 100×.

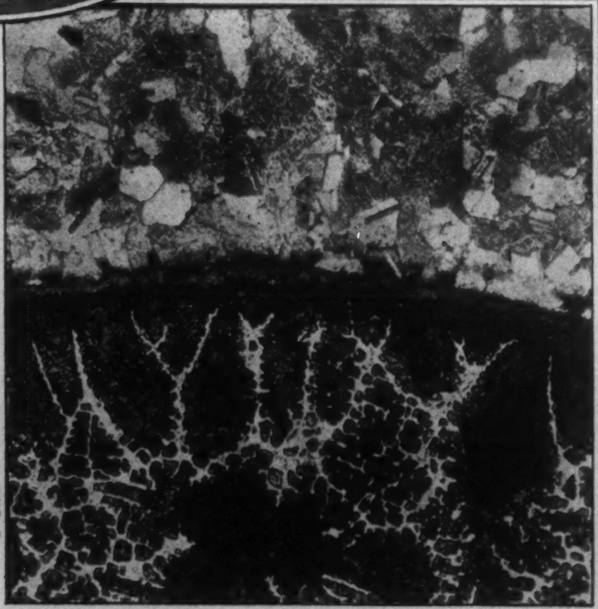


Fig. 4B. Copper and solder containing 20% Silver, 45% Copper, 30% Zinc, 5% Cadmium. 1/2 hr. at 1600° F. Mag. 100×.

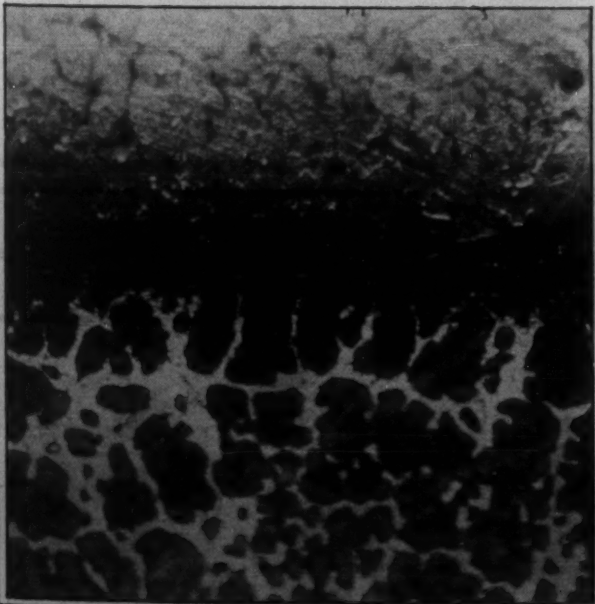


Fig. 4 C. Iron and solder containing 20% Silver, 45% Copper, 30% Zinc 5% Cadmium 1/2 hr. at 1600° F. Mag. 250×.

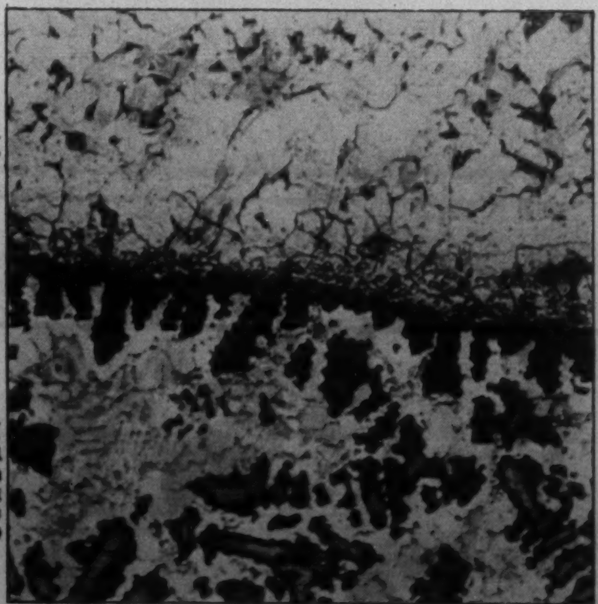
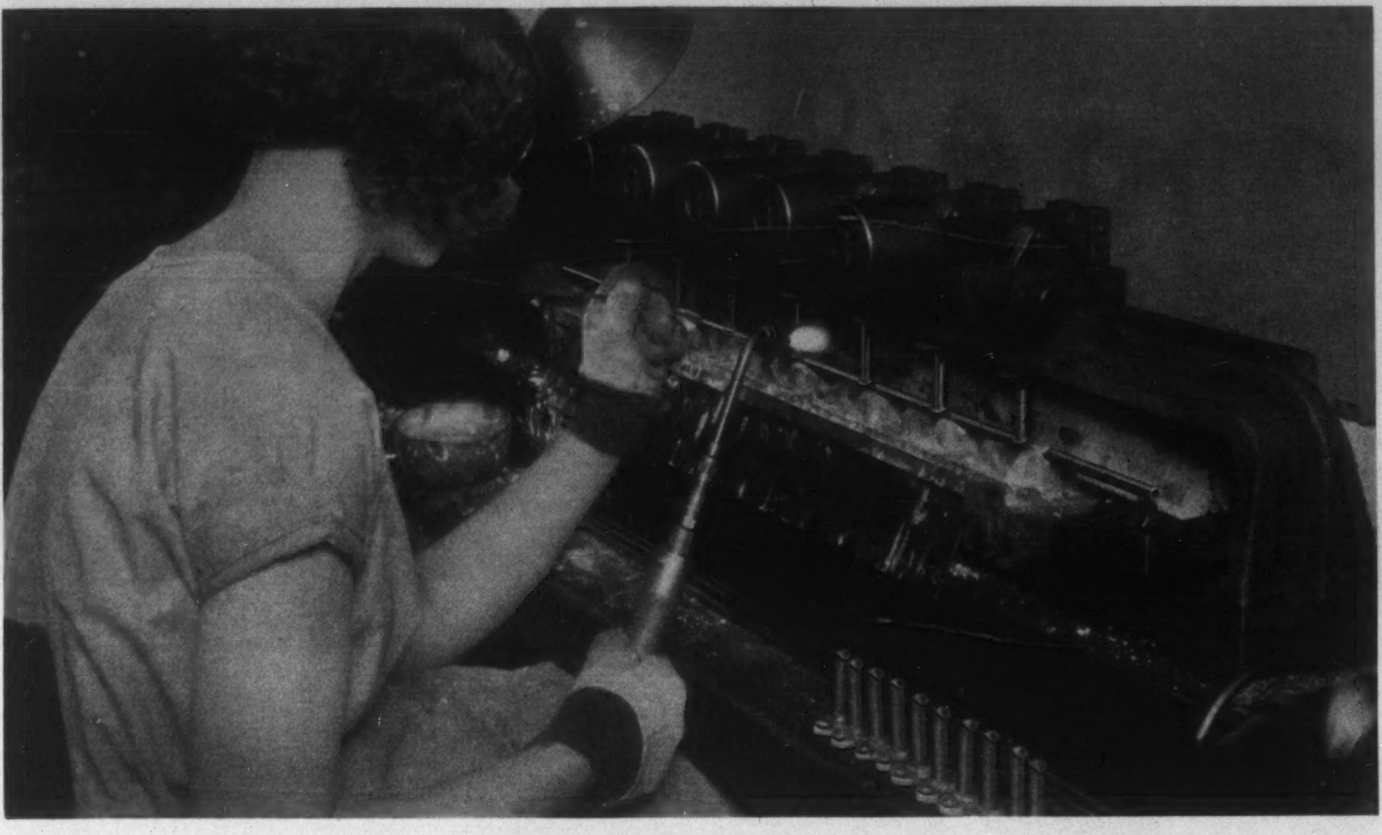


Fig. 4 D. Iron and solder containing 40% Silver, 30% Copper, 28% Zinc, 2% Nickel. 1/2 hr. at 1600° F. Mag. 250×.



Brazing automobile manifold.

films and poor joints will be the result. This point does not seem to be realized even by skilled men, who have been brazing metals for many years.

Before applying the flux it is important to see that the joints are clean. In addition to this, well fitted joints will materially help and will reduce the amount of solder required.

Proper jigs for holding the parts are also a factor which is not given enough attention. Wherever possible, the workman should be free to devote his entire attention to heating the joint properly and being ready to bring the solder under his torch as soon as the required heat is reached. He only has two hands and if he is trying to hold the pieces together and at the same time handle the solder and the torch, best results cannot be expected.

Two of the complaints most often heard in regard to the use of brazing alloys and silver solders is "balling up" and pin holes. If the right grade of solder has been selected, the joint cleaned, well protected with flux and then brought to a temperature above the flow point of the solder there will be no balling up. When this trouble does occur, the tendency on the part of the workman is to apply more heat, thinking that he will overcome the difficulty, whereas the chances are that the balling of the solder has forced part of the solder above the flux line, and the added heat is only going to increase the oxidation. In addition, this high temperature is likely to cause the solder which has already joined to diffuse rapidly into the parts and in extreme cases, holes will be eaten into the metal. The remedy for "balling up" is to put more flux on the solder and along the joint and then heat the joint long enough for the flux to dissolve any oxide films that have formed. As soon as the oxides are dissolved by the flux it will be found that the solder will flow freely.

Pin holes may be due to several causes; dirt, inclusions of flux, improper heat and oxides are some of the most common. The basic factors governing successful work are so simple that it would seem unnecessary to constantly repeat them, but experience has shown that simple as these fundamental principles are, they are often neglected or only partially understood. It should be remembered that in making soldered joints we are really producing relatively thin castings. We all know what great care is taken in making castings to have proper gating and a sufficient number of runners so that the metal will flow freely and gases, dross or foreign matter will escape from the metal before it sets. In using silver solders we often flow them for considerable distances along the joints and the effect of the capillary action is quite dependent upon the fluidity of the flux and the solder. In the case of welding with bronze

Silver brazing on radiator.

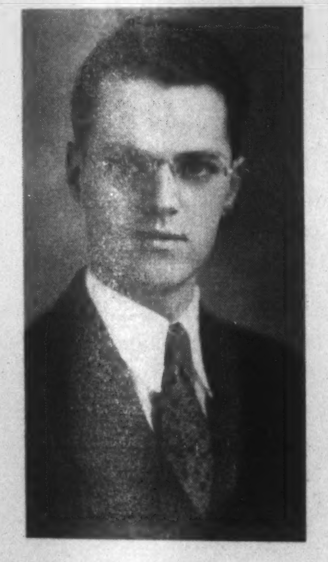
or brass welding rods of low melting point the conditions are quite different. The casting is of relatively large size and the metal is flowed on in successive layers, thus giving an opportunity for inclusions to rise to the surface, and the unequal heating which may occur in the long silver soldered joints does not occur. Many times when a long joint is to be soldered, one part will be heated more than another and if the joint as a whole is not heated to a point above the flow point of the solder, it is quite possible that inclusions of flux or oxides may occur in the cooler sections. Also the solder itself may not flow properly or remain liquid long enough for bubbles of gas to escape and pin holes will result.

There is a feeling among some persons that high zinc solders are a source of pin holes, because of the volatilization of the zinc. When it is considered, however, that only the lowest grade silver solders have these high percentages of zinc and even those have less zinc than ordinary brazing alloys, it is difficult to logically account for this feeling. For example, No. 1 silver solder A. S. T. M. specification contains 10% silver, 52% copper and 38% zinc, whereas the common spelter solders contain in the neighborhood of 50% zinc, and the bronze welding rods approximately 40% zinc. Many experiments have been made in regard to the use of high percentages of zinc in silver solders and where heating and fluxing conditions are carefully controlled no evidence can be found of excessive pin holes or defective joints. More care in the use of flux and application of the correct amount of heat will eliminate most of the troubles from pin holes.

Silver solders will flow into very narrow openings and the strongest joints can be made with a small amount of solder. With the present low price of silver and the proper supervision of the use of silver solders to prevent waste, even the first cost of the amount required to make strong joints will compare favorably with base metal brazing alloys. The low flow points of silver solders give the added advantage of less time for heating and less chance for damage from overheating the parts to be joined.

More detailed information regarding the use of silver solders is given in the Proceedings of the American Society for Testing Materials, Vol. 30, Part 2, 1930.

◆ ◆ ◆ ◆ ◆



The first part of the extensive research program conducted since 1929 by the Michigan College of Mining and Technology on the copper cuprous oxide system has received noteworthy recognition by the recent award of the Alfred Nobel prize, newly instituted, to **Corbin T. Eddy,** assistant professor of physical metallurgy at the Michigan college, for his paper on "Arsenic Elimination in the Reverberatory Refining of Native Copper."

The second unit in the Michigan Tech. metallurgical research project, a study of the copper silver system, was begun some months ago. At the same time Assistant Professor Roy W. Drier started his investigation of the correlation of the physical properties of mechanically deformed copper products with their ultimate structure as revealed by the X-ray. Other members of the staff engaging in research under the general direction of Professor A. T. Sweet, department head, are Associate Professor N. H. Manderfield and Research Engineer Frank Tolonen, aided by several of the younger instructors.

F. J. Griffiths, formerly president of the Republic Research Corp., has been elected director and president of the Timken Steel and Tube Co. M. T. Lothrop, president of the Timken Roller Bearing Co., has been made chairman of the board of the Timken Steel and Tube Co.

Homer J. Buckley, President of Buckley, Dement & Company, Chicago, Ill., delivered an address before the Steel Founders' Society of America, Inc., on the subject of "Straight Line Methods to Sell Steel Castings." A discussion on the principle of Firm Bidding, was also presented by Arthur Simonson, Vice-president of The Falk Corp., Milwaukee, Wis.

Dr. Marcus A. Grossmann, formerly Vice-president of the Republic Research Corp., a subsidiary of the Republic Steel Corp., is stationed at the Illinois Steel Company as a representative of the United States Steel Corp., General Research Laboratories.

E. R. Dougherty has joined the Amsco Sales organization, and will work with Mr. E. F. Mitchell, District Manager, in the engineering and sale of Fahralloy castings in Chicago and the surrounding territory.

Dr. Samuel W. Stratton, chairman of the corporation of the Massachusetts Institute of Technology, died suddenly, Oct. 18, 1931.

Dr. F. N. Speller, a member of the Editorial Advisory Board of METALS & ALLOYS, chairman of the Metallurgical Advisory Board, Director of Metallurgy and Research of the National Tube Company, Pittsburgh, was awarded the American Iron and Steel Institute medal which is given annually for the best technical paper of the preceding year. Dr. Speller was presented with the medal for his papers on Corrosion in Structural Steel, given in October 1926, and on Coöperative Research in the Iron & Steel Industry presented in May 1931.

◆ ◆ ◆

Calendar of Meetings

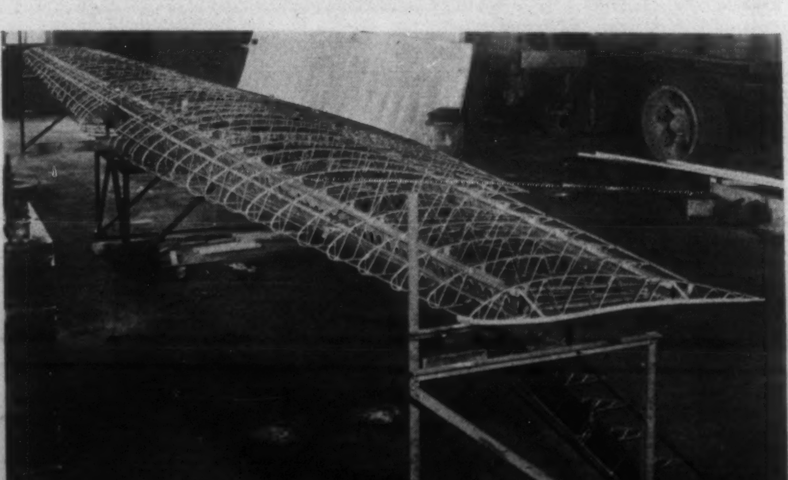
Third International Conference on Bituminous Coal, Pittsburgh, Pa., Nov. 16–21.

American Society of Mechanical Engineers, Engineering Societies Building, New York, N. Y., Nov. 30–Dec. 5.

American Institute of Chemical Engineers, Atlantic City, N. J., Dec. 9–11.

Steel Founders' Society of America, Inc., Pittsburgh, Pa., Dec. 10.

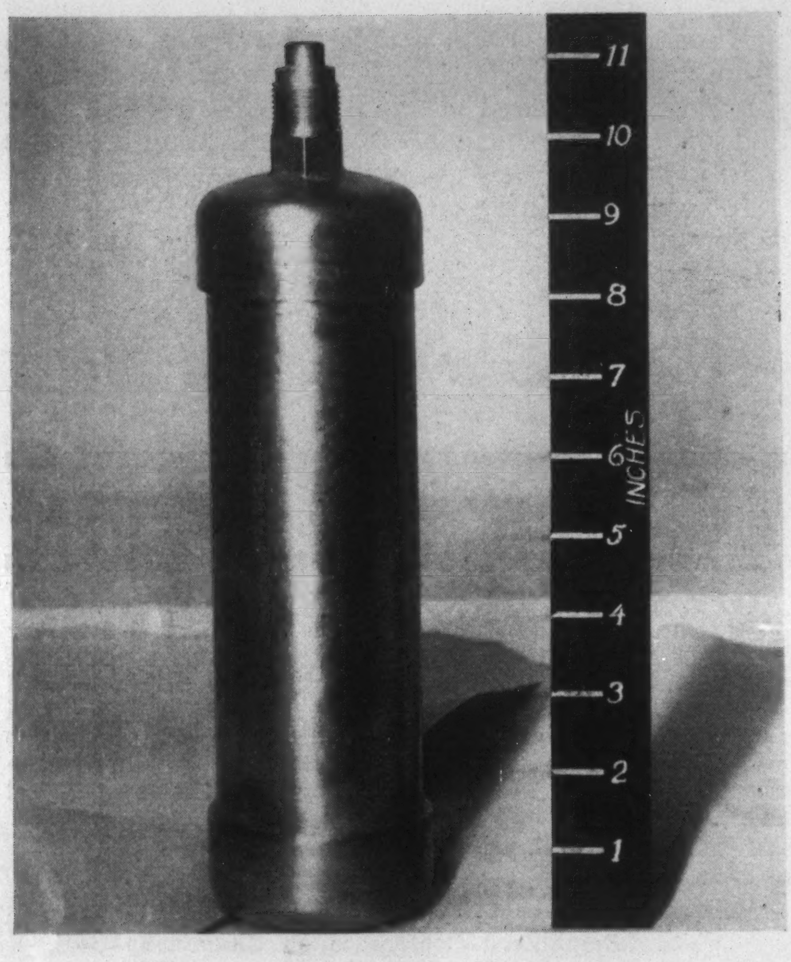
◆ ◆ ◆



Aeroplane wing frame of Allegheny metal. A plane with this wing is now undergoing test flights at Roosevelt Field, Long Island. Tests indicate twenty-five percent greater strength, with the additional safety factor due to elimination of corrosion. The wing and plane built by Fleetwings, Inc.

Copper Brazing in Controlled

ANYONE who has poured a heat of molten copper in air would be amazed at the fluidity of molten copper in a hydrogen atmosphere, and the way it will crawl by capillarity into the tiniest crevices. Upon this property is based an industrial development in the joining of metals that bids fair to increase greatly.



Monitor tester for gas under pressure.

THE practicability of copper brazing in controlled atmosphere electric furnaces is being demonstrated by the reliance placed in the process by several manufacturers. Their entire production of certain lines is built around this method of assembly. Some of the results obtained by this rather unusual manner of brazing are set forth in this article.

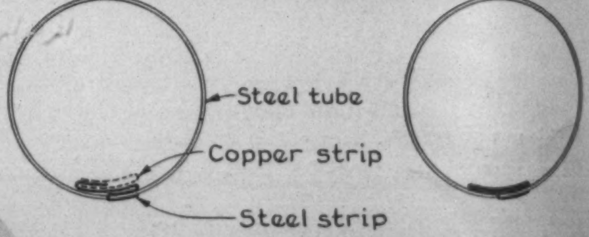
The procedure followed is to assemble the steel parts in a suitable manner and apply copper near the joints in the form of wire, chips, paste or powder. The objects are then heated to a temperature above the melting point of copper in an electric furnace with reducing atmosphere. In this atmosphere light oxide films are cleaned from the steel surfaces and as the copper melts it flows readily on the hot clean steel, being drawn into joints by capillary attraction. Flux in this process is therefore unnecessary under ordinary circumstances.

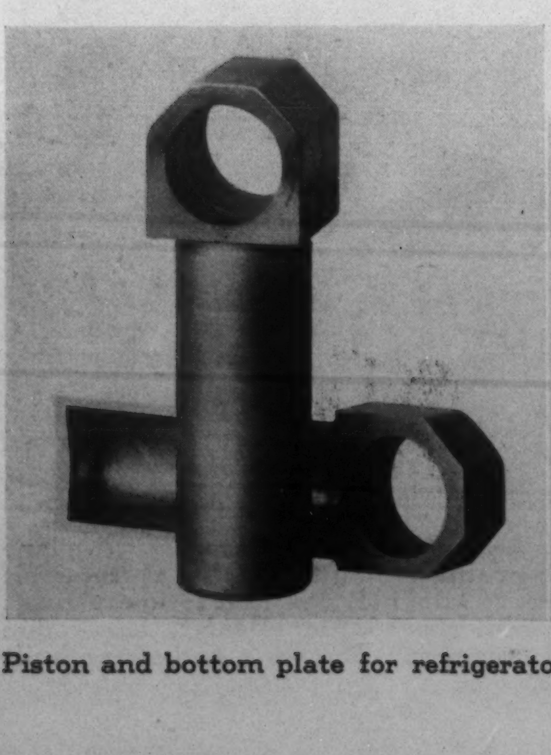
One manufacturer, The Horton Mfg. Co. of Bristol, Conn., has been copper brazing steel golf club shafts for about ten years. These golf shafts are made of high carbon steel so that suitable characteristics can be obtained from heat treatment. Steel strip with about 1.00% carbon is used by this manufacturer for the purpose, insuring uniformity of carbon distribution throughout the shaft. Only a slight amount of de-

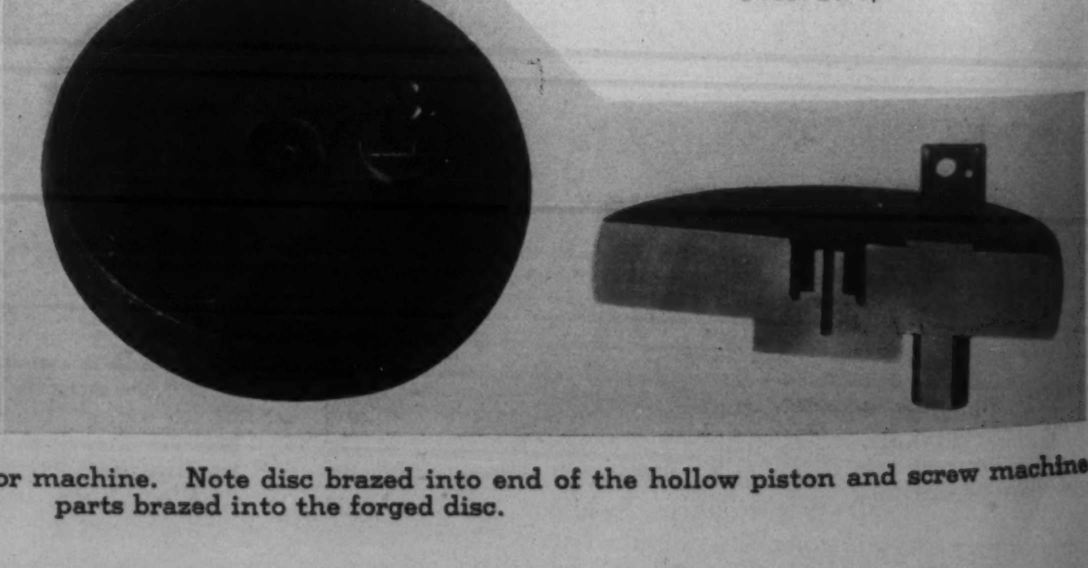
---

* Industrial Department, General Electric Company.

Copper brazed steel golf shaft; and cross section before and after brazing, showing copper-bearing steel strip drawn into joint.







Piston and bottom plate for refrigerator machine. Note disc brazed into end of the hollow piston and screw machine parts brazed into the forged disc.

Atmosphere Furnaces

BY H. M. WEBBER*

The commercial success of tungsten carbide tips for tools would be greatly limited were not this method available for brazing them to the shank.

This is a notable example of the fact that anything with an outstanding property is almost sure sooner or later to find a useful application depending directly upon that property.

carburization occurs at the surface of the steel because of the hydrogen in the atmosphere, as the shafts are not exposed long enough in the heat to permit much reaction.

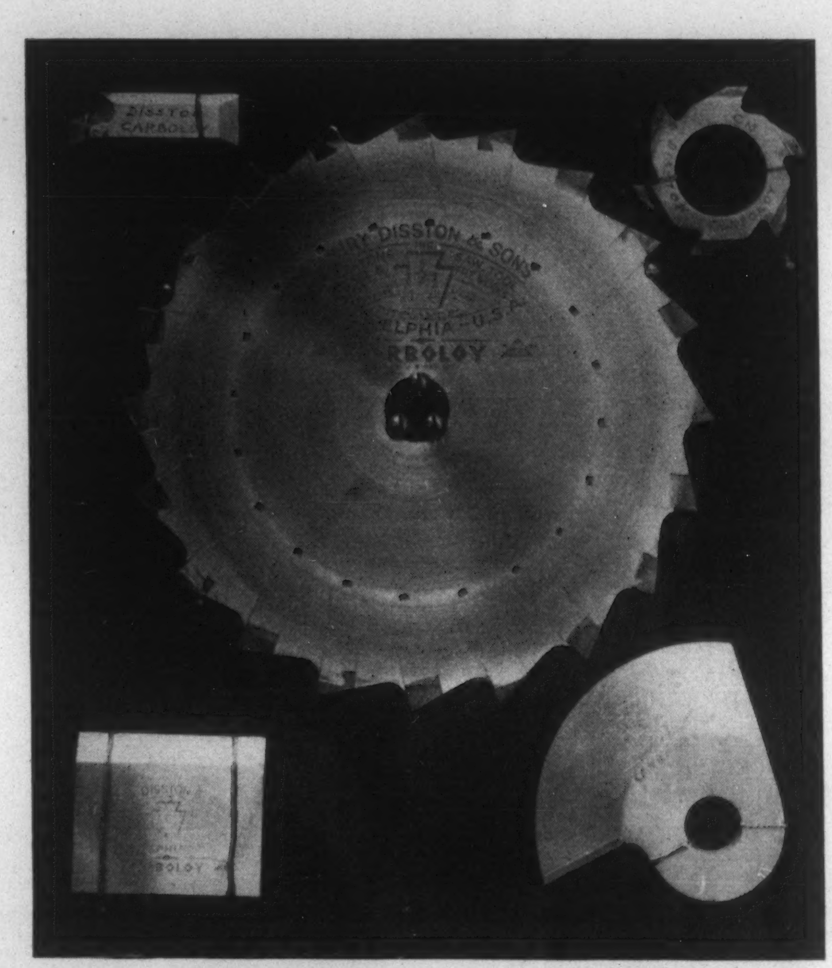
The tapered shaft is first formed with a butt joint and then a steel strip is threaded into the seam. This strip overlaps the inner wall areas adjacent to the joint, and carries a piece of copper which ultimately serves as the bonding material, a patented feature.

When a shaft thus prepared is placed in the controlled atmosphere furnace at 2100° F. the copper melts, flows into the joint, forms metallic solutions with the steel, and solidifies within the crevices upon cooling. A union of excellent strength is thereby produced.

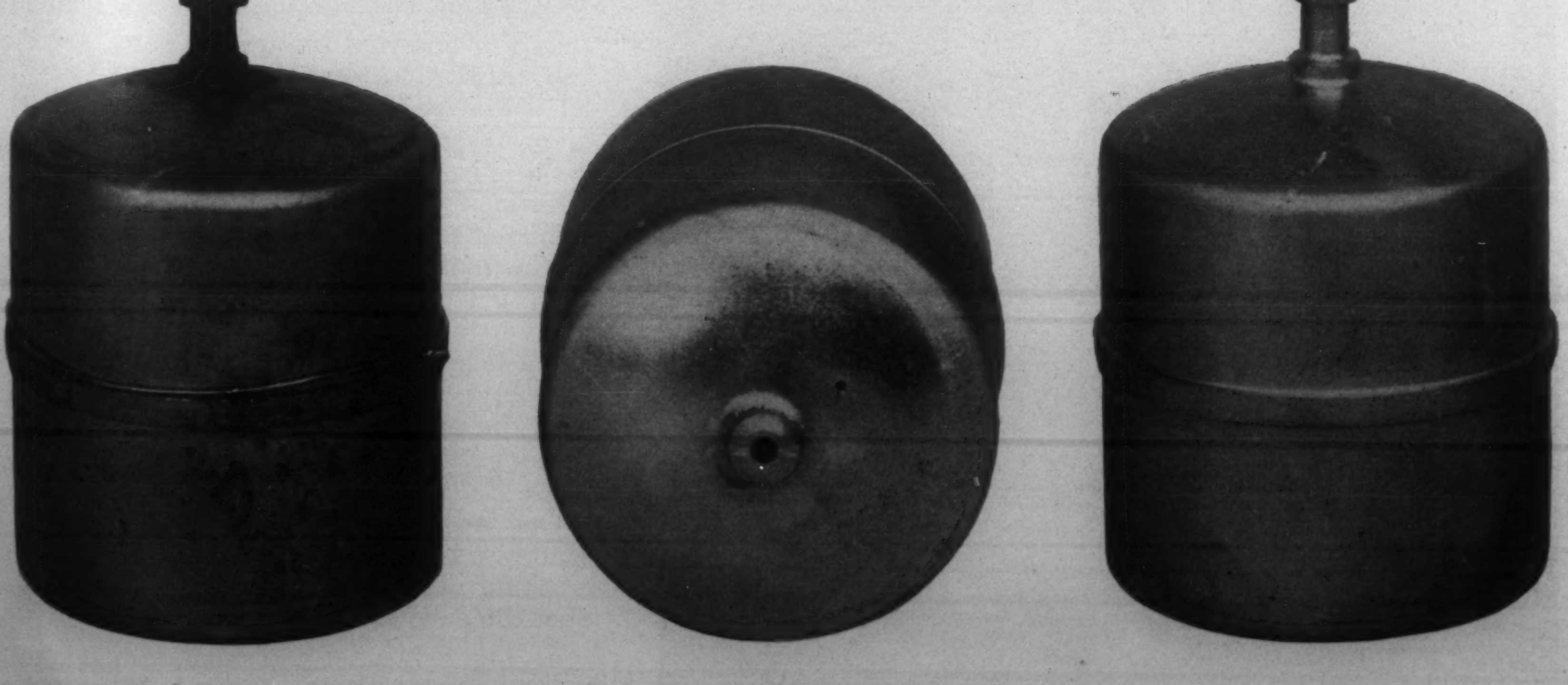
After the shafts are brazed they are normalized to restore the grain structure, then hardened and drawn. Copper plating is commonly used for finishing off the appearance and giving protection to the steel surface.

A battery of four furnaces is used for this brazing production, all of which are practically identical. The furnaces are of the muffle type, the muffles being "D" cross section alundum tubes about 10″ wide by 4″ high, by 22″ long. A spirally wound molybdenum wire resistor is wrapped about the tube, and maintains the necessary temperature within the chamber.

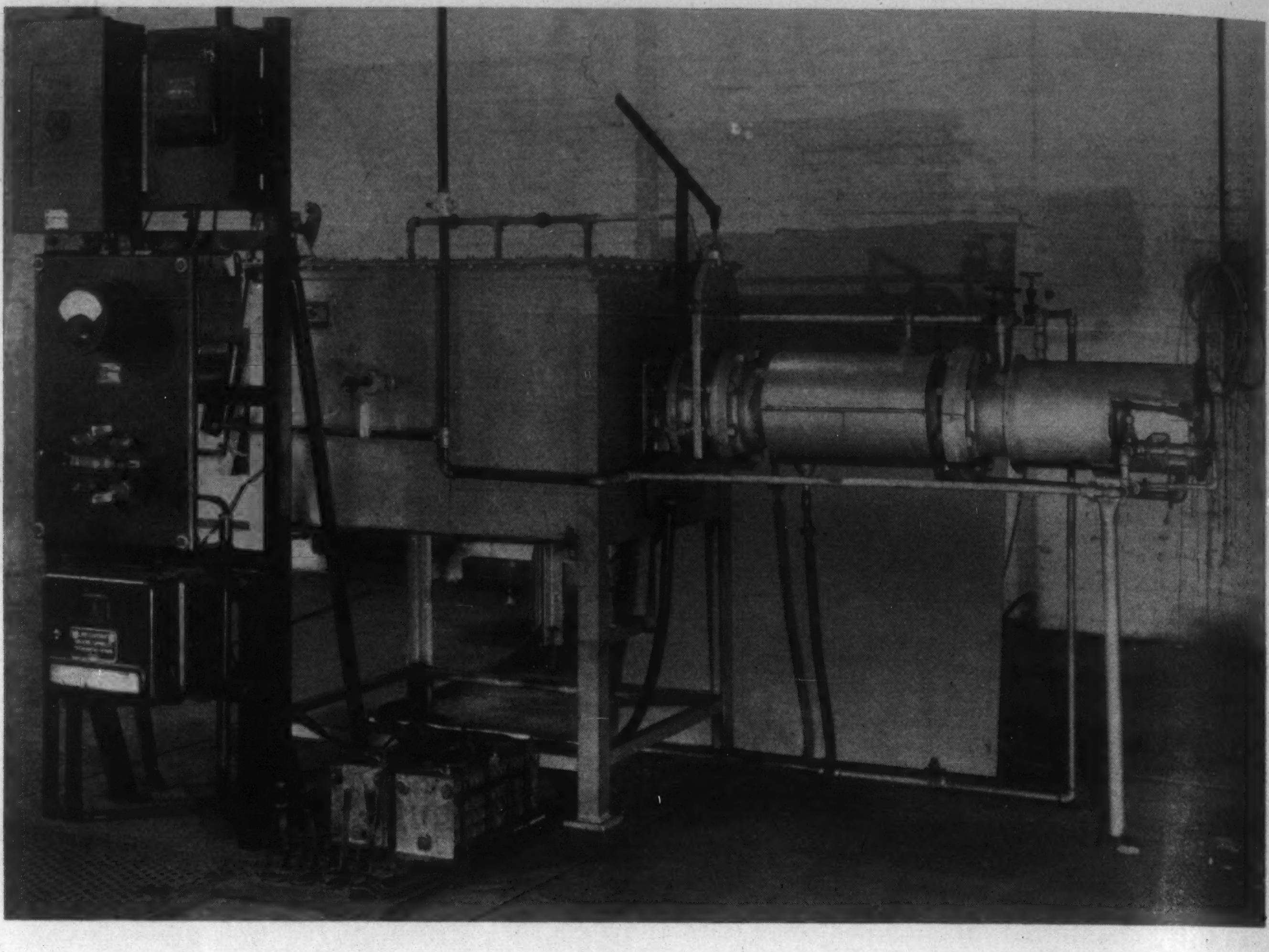
A water-jacketed chamber, also having a controlled atmosphere, is mounted at the outgoing end of the



Carboloy tipped tools, copper brazed.



Refrigerator float before and after copper brazing.



Electric furnace for copper brazing tungsten carbide-alloy tools in controlled atmosphere.

heater. An oil discharge seal provides an outlet for the work.

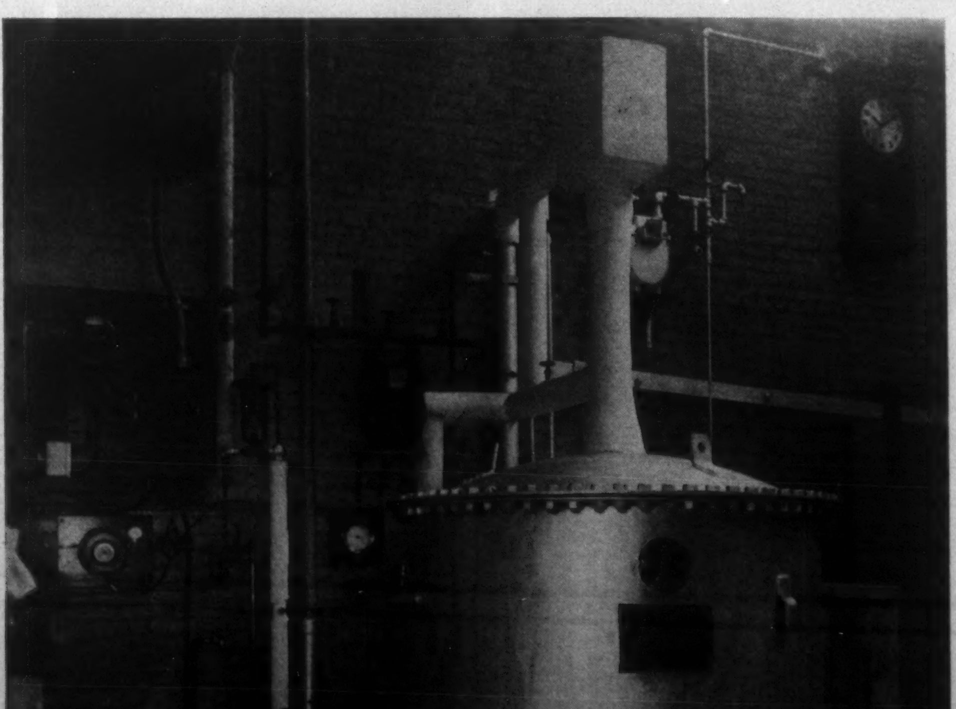
In production, 8 shafts are slowly pushed into the furnace, by a mechanically operated pusher, on a charging cycle of about 6 minutes. The brazing is thus accomplished in a semi-continuous manner. The front end of the furnace is always open to accommodate the shafts and charging mechanism, and the discharge end is always closed by the oil seal.

The controlled atmosphere used within these furnaces is Electrolene (a gas composed largely of hydrogen and carbon monoxide). It is made in this manufacturer's plant by re-forming city gas with heat and steam. The Electrolene producer is a vertical cylindrical electric furnace, having within its chamber a suitably designed retort for directing the flow of gas. The operating temperature of the producer is about 2000° F. Operation is entirely automatic and the equipment needs little attention other than that required for starting up and shutting down.

Another application for copper brazing has been found in the manufacture of tungsten-carbide-alloy tools. One vendor in particular, Henry Disston & Sons, Inc. of Philadelphia, Pa., is developing an unusual family of inserted tooth saws, circular cutters, radius cutters, planer tool bits, etc., all of which are tipped with tungsten carbide alloy inserts. This new technique in tool making is, of course, being looked upon with interest.

Bits of tungsten-carbide-alloy are inserted in the tools and held in place. Copper is then added to the assembly in one of the convenient forms and the objects are charged into the furnace on a tray. In this instance the molten copper joins readily with the cobalt binder and the steel shank, forming a good bond for holding the inserts in place.

One advantage of this method of assembly over welding is that checking or cracking of the bits is less likely to occur. Such difficulty has been encountered at times



Electrolene Producer rated 300 cu. ft. output, 25 Kw. connected load.

because of the difference between coefficients of expansion of the two metals, but with uniform heating and relatively slow cooling rate within an electric furnace, this danger is not so imminent when copper brazing. Appearance is also a factor to be considered.

The furnace used by the above tool manufacturer has a heating chamber 6″ wide × 4″ high × 24″ long, and the cooling chamber has the same working dimensions. A sliding fire clay heat baffle and a gas tight gate valve are both built in between the heater and the cooler to be opened when transfer of work from the heating chamber to the cooler is effected. Work is charged on trays 6″ wide × 14″ long. The front door slides at an angle on a cast-iron door frame, effectively sealing gas within the furnace, and the back door is of the hinge and latch type. The resistors are molybdenum wire, wound sinusoidally in loops on alundum slabs. These slabs in turn are mounted on the side walls, allowing direct radiation of heat from resistor to the work.

Still another manufacturer, building electrical equipment, is using copper brazing in the fabrication of parts for electric refrigerator machines and other miscellaneous devices. Common requirements for this type of work are that the parts have gas tight joints which will withstand reasonably high pressures. These requirements are easily met by the copper brazing process.

If objects are assembled tightly to begin with, little difficulty is encountered in having the copper flow into the joints. As a matter of fact, the results improve as tightness increases, because molten copper is very fluid and is readily drawn into small crevices by capillary attraction. In this respect it is worthy of note that no gap needs to be left for the occupancy of copper. It has been found that metal to metal joints, such as a press fit, are easier to braze by this method and have properties superior to those loosely assembled.

Drawn steel shapes lend themselves nicely to such construction, because they can frequently be put together with sleeve or interlocking joints. Refrigerator floats and check valves are common examples. Floats, which in many instances are made of brass or copper, and silver soldered by hand, are inexpensively made by using steel instead of a non-ferrous metal. All joints, of course, are brazed simultaneously in one passage through a furnace. Check valves of complicated construction, which would ordinarily involve an elaborate casting, can similarly be assembled from simple shapes and subsequently be copper brazed, in one pass.

Refrigerator evaporators are being fabricated in large quantities by utilizing the conveniences of both copper brazing and atomic hydrogen welding processes. Pressed steel parts are assembled with copper wires threaded through the inside, adjacent to the joints (ten in number), and then the end pieces as well as two longitudinal seams are atomic hydrogen welded. The assembly is thus rigid and almost complete. Upon passage through a brazing furnace, the copper is melted into the ten inside joints and the evaporator is ready to be sent further along into the line of production.

Another object copper brazed with success is a "gas bomb" designed to hold small quantities of the refrigerant used in ice machines. The gas is carried in these compact portable bombs at 200 lbs. pressure, and is used in servicing the machines. These containers are made up of short lengths of seamless steel tubing, on each end of which a cap is tightly pressed. In one of the caps a screw machine part is inserted, for tapping off the gas. The three joints are then copper brazed by wrapping copper wires adjacent to the seams standing the objects on end on a support, and passing them through a copper brazing furnace.

Several furnaces have been developed for refrigerator copper brazing work, the most recent ones being the semi-continuous tunnel type. The bolted cover type and the hood or bell type have also been used for years. Continuous furnaces are ordinarily designed for one class of work, production usually warranting such an installation. The important feature of such furnaces is that a throat is used at the entrance and exit ends of the heating chamber, which, if designed closely to outline the work passing through it, will minimize the heat losses at these points.

◆ ◆ ◆

According to a research report published by Mellon Institute of Industrial Research, Pittsburgh, Pa., a novel heat-reactive molding compound is now being produced commercially in the plant of Toledo Synthetic Products, Inc., Toledo, Ohio. This new urea-base compound, called "Plaskon," was evolved at Mellon Institute under a series of Industrial Fellowships sustained by the Toledo Scale Company. Copies of the report may be obtained by interested persons upon direct request to the Institute.

Fabricated "Plaskon" is described as unexcelled in color possibilities, combining bright colors with a hard, lustrous surface. Its base shade is one of neutral translucency, permitting pigmenting to give all colors of any intensity, either opaque or translucent. Obviously, as indicated in the publication, infinite variations in mottled or striated effects are possible.

The mechanical and electrical properties of "Plaskon" are said to be excellent; they are summarized in the report.

◆ ◆ ◆

At the National Metal Exposition in Boston on September 21, the Heppenstall Company introduced their "HARDTEM" Razor Blade. They stated it was particularly fitting that it be announced at a *Steel Convention*, for "HARDTEM" is the first blade in this country to be produced and marketed by a steel manufacturer.

◆ ◆ ◆

For many years **The Ajax Metal Company,** Philadelphia, operated an electric furnace department which manufactured electric melting furnaces now successfully used in large numbers throughout the world. The early part of 1931 this department was divorced from the parent company and is now operating as the **Ajax Electric Furnace Corporation,** 1108 Frankford Ave., Philadelphia; and manufactures a line of induction melting furnaces.

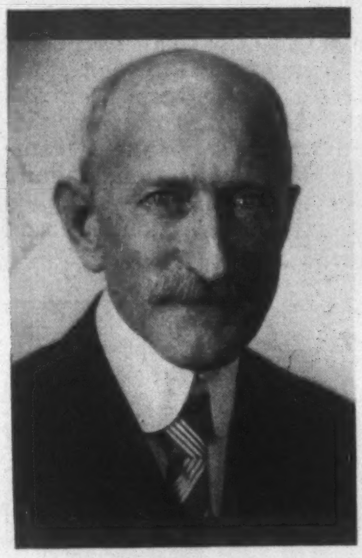
At the same time a new division was formed and incorporated under the laws of Pennsylvania known as the **Ajax Electric Company, Inc.,** Frankford Ave. and Allen St., Philadelphia, for the manufacture of electric heat treating furnaces, and kilns. Mr. G. H. Clamer, President of The Ajax Metal Company as well as the Ajax Electric Furnace Corporation, is also president of this new division. Mr. William Adam, Jr., who has been affiliated with the electric furnace interests of the parent company for the past twelve years, is vice-president; and Mr. John E. Haig is the secretary and in charge of engineering. The Ajax Electric Company has, also, affiliated itself with two of the most prominent European manufacturers of electric heating treating furnaces; namely, The Electric Furnace Company, Ltd., London, and the Hirsch Kupfer & Messingwerke, Finow, Germany. It is thus in contact with all new developments in this country as well as Europe, effecting the electric heat treating furnace field.

The Ajax Electrothermic Corporation, Trenton, N. J., who manufacture the Ajax-Northrup high frequency induction furnace, is also an affiliated company.

The Ajax Metal Company in following this policy of diversification, which is in striking contrast to the more common trend to-day of merging, fully realizes the additional overhead involved in maintaining separate buildings and staffs for the various enterprises, but feels that this additional expense will be more than offset by the greater concentration made possible on melting and heat treating problems which, by their very nature, are separate and distinct processes, and by the more prompt and efficient service which each unit can render to users of their respective equipment. At the same time this combination of Ajax companies makes available an interchange of engineering knowledge on problems peculiar to their respective fields.

The Midvale Research Laboratory

BY RICHARD RIMBACH



John L. Cox
Ass't. to the President.

Francis B. Foley
Director of Research.

SOME day the writer expects to visit and write up for Metals & Alloys a metallurgical laboratory which is wholly new—which is without background. It will be a new experience. The Midvale Metallurgical Laboratory certainly does not fall into that category. Out at Ferncliff Park they will proudly tell you that back in 1872 Midvale hired a European trained chemist by the name of Charles A. Brinley; that in 1875 Midvale devised a drop test for axles, using by chance a 1640-lb. ram, which weight is now standard; that in the same year they made the first quenching experiments on ordnance steel; that in 1892 they improved Brulstein's process for armor-piercing projectiles; that Frederick W. Taylor was Chief Engineer of Midvale; that when the Navy suddenly became enamored of nickel steel in the early nineties Midvale was able to meet its rigid test specifications with carbon steel; that in that same decade John L. Cox set up at Midvale a metallographic microscope equipped for vertical illumination and a Roberts-Austen critical temperature recorder; and that Midvale built in 1901 a small but real metallographic research laboratory, and sent young engineers to Paris for training under Osmond, Le Chatelier and Guillet. In that small but efficient laboratory the Siemens calorimetric pyrometer was improved and made much more accurate, and it was there that Radclyffe Furness inspired the development of the Leeds & Northrup recording potentiometer pyrometer.

This interest in pyrometry is, to the writer, one of the most interesting features of the new laboratory. Suffice it to mention that the Midvale research staff bows to no other outfit in so far as thermocouple calibration is concerned. The latest device installed there, for instance, is a calibrated wide filament lamp for checking optical pyrometers. . . .for checking more accurately and often.

The building itself is three stories, 50 feet wide, 100 feet long, and entirely of brick and concrete. The supporting members and all floors are of heavy reinforced concrete. Double-faced glazed brick and metal partitions are used throughout except in the Chemical Laboratory, where glazed wooden partitions are used to combat acid fumes. The building is therefore practically 100% fire retardant. Exterior walls are of mottled shades of red rough texture brick. All except the basement rooms have buff-colored glazed tile wainscoting, presenting an attractive as well as a sanitary background for the various equipment.

The plans were drawn up by United Engineers and Constructors, Inc., but as far back as 1910 Dr. H. L. Frevert visualized and drew sketches of the "ideal chemical and metallurgical laboratory." In addition to gas, compressed air, steam, hot, cold and fire service water, there is an impressive labyrinth of electrical service for telephone, telautograph, etc., including: 6 and 40 volts d. c. battery service for instruments; 230 volts d. c. for all motor power; 110 volts, 3 phase, a. c., for lighting; and 220 volts, 3 phase, a. c., for resistance heating and high frequency melting furnaces.

The equipment is the most modern obtainable. Chemical work benches, storage cabinets and instrument tables are all made of lead-coated copper-bearing steel, with an acid and alkali-resisting enamel. The tops of the instrument tables are of alberene stone to insure electrical insulation, and to add weight for steadiness. Laboratory benches, where water and chemicals are used, also are topped with alberene stone.

One of the illustrations shows the high-frequency induction furnace for experimental melting, which is of 20 kw. capacity and melts fifteen pounds of metal in thirty minutes. In response to the modern demand for high-pressure high-temperature steels, the creep testing equipment is said to be the latest word. It consists of a battery of 10 creep units with individually controlled furnaces. In each of these, specimens of steel are loaded for long periods, perhaps continuously for 6 months or a year in order to determine the slow rate of deformation to an accuracy of 0.00001 inch. Not only is temperature control automatic but provisions are made for uniform heating of specimens with adjustments by spacing the winding and insulating the furnaces. For work at ordinary temperatures there is a Baldwin-Southwark hydraulic testing machine of 60,000 pounds capacity with a Martens-Tuckerman extensometer capable of measuring deformations of the order of 2 millionths of an inch in 2 inches.

Rockwell, Brinell and Scleroscope Testers.

Induction Melting Furnace (15 pound capacity).

Leitz Microscope.

Left to right: Thomas A. Makem, F. Reisinger, George W. Bruce, John Rhodes, F. Houghton, Martin Mabrey, F. B. Foley, Gabriel Heckel, Thomas Eagan, William Kahlbaum, Walter D. Weikel, T. F. Schaeffer.

Heat Treating Room.

Baldwin Southwark Hydraulic Testing Machine.

A latest model Leitz outfit furnishes photomicrographs up to 3000 diameters. In conjunction with this the polishing equipment consists of 3 motor-driven horizontal wheels with varying speed control from 300 to 3000 r. p. m. The grinding equipment consists of a 23-in. vertical disc grinder. To facilitate the production of good photographs a modern dark room is provided on the first floor.

The heat treating equipment of the metallurgical research department consists of three semi-muffle gas furnaces, a small high temperature furnace, a salt bath and three automatically controlled electric furnaces. The gas furnaces are all arranged under a hood provided with suction draft. For efficiency, accuracy and safety, these furnaces are all controlled from a bench near one end of the hood. The electric furnace equipment consists of a new medium-sized electric furnace, capable of being automatically controlled to ± 2° F., a small bench furnace, and a vertical cylindrical furnace. The latter two are so connected that their temperature may be automatically or manually controlled. The quenching tanks are mounted on wheels, so that they may be placed close to the furnace where quenching is to be done.

The study of corrosion of metals is carried on in a separate room, furnished with the usual chemical equipment, salt spray baths, etc., and a chemical hood in this room is so constructed that the heavy gases, such as chlorine, bromine, etc., may be handled safely.

The expansion of metals with temperature is studied with a Rockwell Dilatometer. With this machine critical temperatures and coefficients of linear expansion are quickly determined; it will also serve at times for heat treating small pieces.

In addition to the new equipment described above, the laboratory is well stocked with a precision Leeds & Northrup potentiometer capable of measuring to 0.0002 millivolt; Brinell, Rockwell and scleroscope hardness testing machines; a permeameter for measuring magnetic characteristics, and Le Chatelier-Saladin and Leeds & Northrup critical temperature instruments.

The chemical research laboratory is on a par with the rest. Located on the top floor are the main analytical laboratory, carbon room, balance room, sample room, fuel room, special research room and vault. The sinks are of Knightware. Forced suction draft is provided through two sets of double hoods of the Cornell type.

Next to the main analytical room is the balance room. The balances rest on felt with plate glass tops. The carbon room has two batteries of carbon combustion furnaces. This room is also provided with a balance table and space to accommodate four balances. A Telautograph furnishes direct communication with the open hearth and electrical furnaces.

The fuel room is equipped for investigation of oil, gas and coal.

The sample and drill room is located in the basement. Tests are received in this room, drilled and the drillings delivered to the carbon room by dumb-waiter. There are two drill presses, a coal grinder and other necessary sampling equipment.

Energizing Action of Carburization of Steel with

BY R. A. RAGATZ[*]

THAT the addition of certain chemicals to charcoal will greatly increase its activity as a carburizing agent for steel has been known for many years. In the "chemically energized" carburizing compounds which are in wide commercial use at the present time, various proportions of sodium carbonate, barium carbonate and calcium carbonate are employed as accelerators.

Despite the recognized importance of the energizing chemicals in case hardening compounds, a review of the technical literature disclosed surprisingly little quantitative or even qualitative information. The experimental data deal for the most part with the carbonates of the alkali and alkaline earth elements.[1,2,3,4] The experiments of Fetchenko-Tschopiwskij[5] cover a greater variety of compounds, but are not as comprehensive as might be desired. The various chemicals which were tested by him were classified as follows: 1. Strongly accelerating carburization: Lithium carbonate; sodium carbonate, oxalate and acetate; potassium carbonate, tartrate, chromate and ferricyanide; barium carbonate. 2. Accelerating carburization: Strontium carbonate; cobalt carbonate. 3. Inert: Calcium carbonate and carbide; magnesium carbonate; manganese carbonate; nickel carbonate; aluminum carbide. 4. Retarding carburization: Sodium sulphate and chloride; potassium sulphate and chloride.

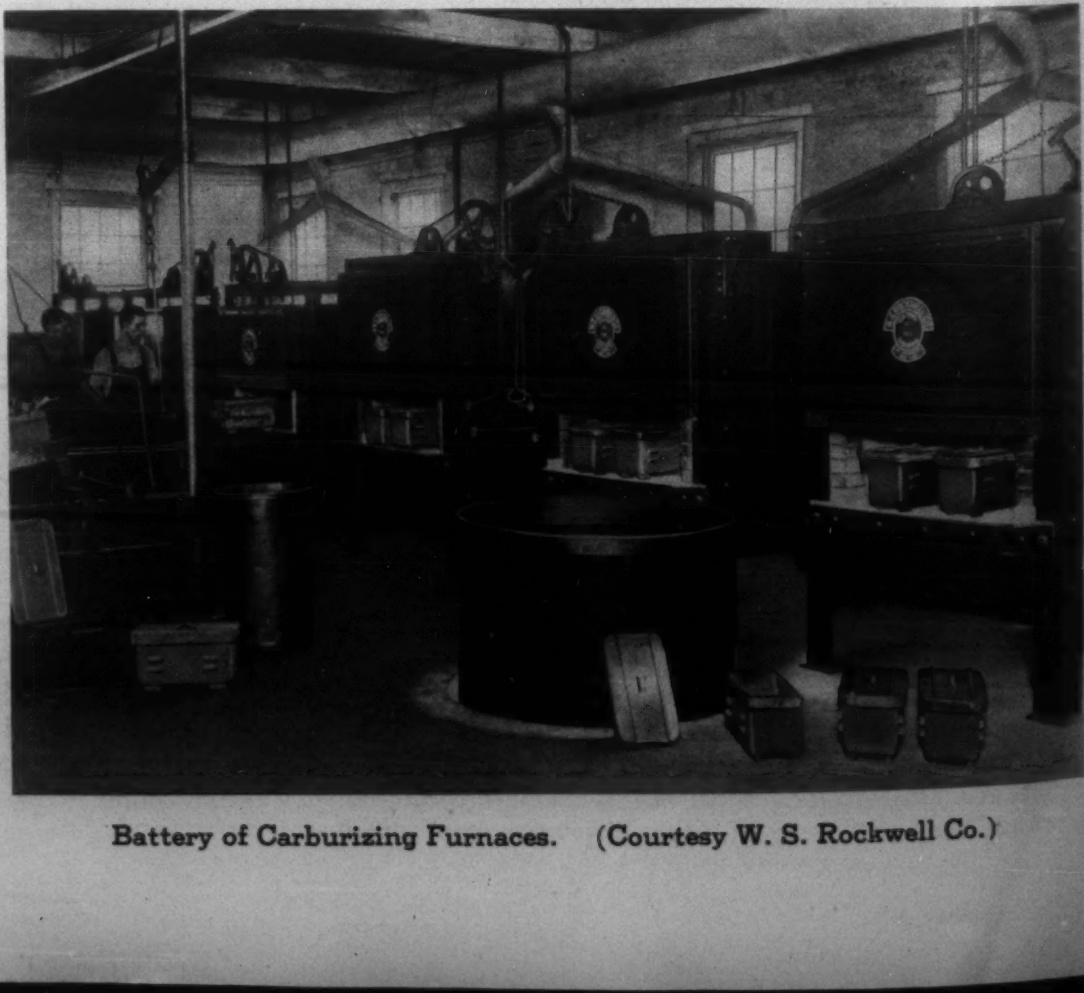
A review of the patent files has shown that numerous chemicals have been patented as energizers. The patent specifications, however, are only suggestive, for very little quantitative information is presented and that is of questionable value. Even from a qualitative standpoint, many of the patent specifications are very misleading.

The work described in this paper was undertaken to provide a comprehensive set of data on the energizing action of a great variety of chemical compounds. Numerous compounds of sodium, potassium, barium and calcium were employed for comparison with the carbonates of the respective elements. When working with compounds of elements other than the four mentioned above, only the carbonate, oxide and hydroxide were ordinarily employed, provided they were available.

A complete solution of the problem undertaken would demand that each chemical compound be tried at various concentrations, temperatures and times for carburization. Due to the large number of compounds it was desired to test, such a procedure would have involved a prohibitive amount of labor and time. It was therefore decided to test each chemical at but one concentration, temperature and carburizing time.

To compare the various energizer chemicals, equal percentages by weight in each instance could be taken as a basis. However, such a basis of comparison leaves considerable to be desired. For example, consider barium carbonate, $BaCO_3$, and barium hydroxide, $Ba(OH)_2 + 8 H_2O$. It is apparent that a comparison of these two chemicals on the basis of equal weights would be unfair due to the large amount of water of crystallization and combined water in the hydroxide. It seemed more logical to proportion the charges in such a way that a definite ratio would exist between the weight of charcoal and the weight of the *element* whose compound was under test. A 25 to 1 ratio was decided upon as being best suited to this work. Accordingly, whenever barium compounds were employed, 75 grams of charcoal were mixed with enough of the particular barium compound being used, to have 3 grams of the element barium present in the mixture. The amount of each barium chemical required was calculated from the atomic weight of barium and the molecular weight of the chemical compound. In the compilation of experimental data in Tables 1 to 9, the percentage by weight of the chemical in each carburizing agent is given. These percentages were calculated to establish a 25 to 1 ratio between the weight of charcoal and the weight of the element under consideration. The few exceptions to this method of proportioning the carburizing mix are noted in the table. The percentages given in Tables 1 to 9 were calculated by slide rule, hence the last place is inexact.

When working with compounds containing 2 metallic



Battery of Carburizing Furnaces. (Courtesy W. S. Rockwell Co.)

---

[*] Chemical Engineering Department, University of Wisconsin.

Various Chemicals in the Solid Carburizing Agents

AND O. L. KOWALKE*

elements, such as sodium chromate for example, 2 carburizing mixes were prepared. In one, a 25 to 1 ratio existed between the charcoal and the sodium, while in the other, a 25 to 1 ratio existed between the charcoal and the chromium.

The 25 to 1 ratio is well adapted to this work, as it gives reasonable percentages by weight for various chemicals. For example, the 25 to 1 ratio demands 5.44% barium carbonate and 8.45% sodium carbonate, each of which is of high enough concentration to exert a strong energizing effect. When working with elements of low atomic weight such as lithium and boron, the proportion of energizer is not excessively high. The 25 to 1 ratio demands 26.05% borax and 17.55% lithium carbonate.

Each carburizing agent was tested at a carburizing temperature of 1750° F. (954° C.) and a total time of 4 hours in the furnace. The temperature selected is at the upper limit of the range used in commercial carburization, but was chosen to permit the use of the relatively short heating period of 4 hours. The temperature of 1750° F. and the total heating period of 4 hours gave a very satisfactory absorption of carbon.

The degree of carburization produced by each carburizing agent tested was gaged by two different methods: (1) The increase in weight per square inch of surface areas (2) The depth of carbon penetration as measured with the microscope.

Steel. The steel used throughout the work was a hot rolled basic open-hearth steel, which was received in the form of $^1/_2$-inch diameter rod. The analysis was as follows:

Carbon	.20%
Manganese	.47
Phosphorus	.016
Sulphur	.029

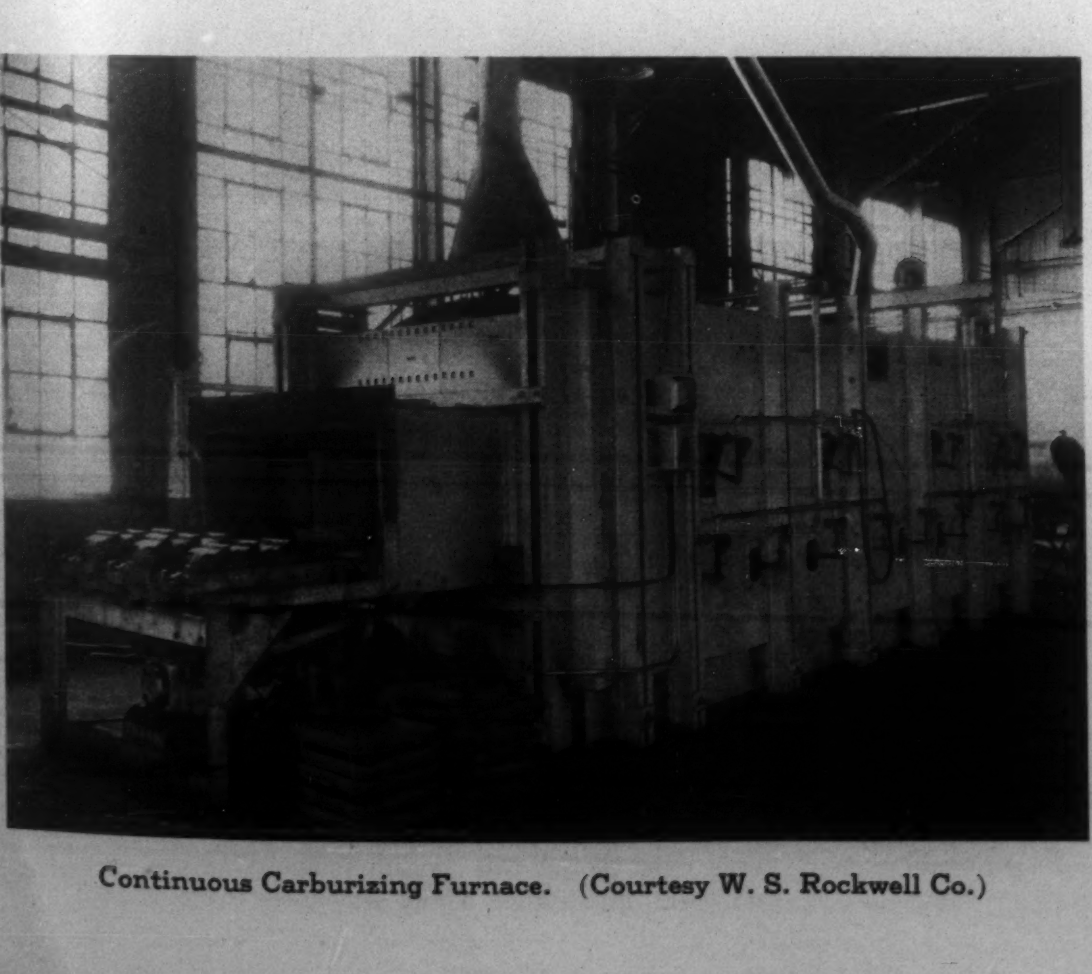
When the steel was carburized, normal cases were produced.

Specimens. The specimens were small cylinders, 1" long and $^7/_{16}$" diameter. To secure a uniform surface in all instances, the specimens were finished with No. 1/0 emery paper. Before being carburized, the specimens were washed in 2 changes of "high test" gasoline and then in 2 changes of 95% ethyl alcohol. They were dried, measured, and then weighed on an analytical balance. The specimens were measured to determine the surface area, as it was desired to express the results on the basis of weight increase per unit area.

Carbonaceous Base. Hardwood charcoal was selected as the carbonaceous base for the carburizing agents. Prior to use it was reduced to a finely powdered form. In order to prevent moisture changes, the charcoal was stored in a metal can having a tightly fitting cover.

Chemicals. The chemicals used, except in the few instances noted in the tables of data, were of "C. P." or "U.S.P." grades, made by reputable manufacturers. Particular care was taken to procure fresh, tightly stoppered bottles of those chemicals which have a marked tendency to absorb or lose water when exposed to the air. In some few instances where the quantity of water associated with the compound was variable, a chemical analysis was performed in order that the carburizing agent could be properly proportioned. All of the chemicals were reduced to finely powdered form just before use.

Mixing the Carburizing Agents. The powdered hardwood charcoal and the powdered chemical were mixed just before using. The proportions were so chosen that in each instance, a 25 to 1 ratio existed between the weight of charcoal and the weight of the *element* whose compound was being tested.



Continuous Carburizing Furnace. (Courtesy W. S. Rockwell Co.)

Retorts. All retorts were made of standard $1^1/_4$" wrought iron nipples 4" long, closed at both ends with gray cast iron caps. New pipe fittings were used for all retorts. To completely remove all traces of oil or thread cutting compounds, the fittings were first washed in "high test" gasoline, and then all surfaces were carefully brushed, taking particular care with the threads. Finally, they were heated at 1470° F. (800° C.) for a short period of time.

To prevent the possibility of error due to contamination from a previous run, only one kind of energizer was used in a given retort. However, a retort was sometimes used a number of times with the same energizer when check determinations were required.

Considerable gas is formed on heating the charge to the carburizing temperature, and rather high pressures are temporarily developed if the retort is not vented. In order to eliminate the explosion hazard from this cause, the retorts were vented by a hole made with a No. 50 drill. Several tests showed that the rate of carburization was exactly the same in vented and unvented retorts. Though the pressure initially developed on heating up an unvented retort is quite high, it falls off rapidly due to the gradual escape of the gas, with the result that for the greater part of the four hour heating period the pressure is atmospheric.

Packing the Retorts. Four retorts were employed for each experiment, and 2 specimens were packed axially into each retort. The powdered carburizing agent was tamped around the specimens, avoiding the use of excessive pressures. The retorts were completely filled with the carburizing agent. The 4 retorts were bound together with heavy iron wire.

Furnace. An electrically heated muffle furnace $7^5/_8''$ wide, $5^3/_8''$ high and 14″ long was used for performing the carburizing treatments. To secure the required degree of temperature uniformity, a plug of Non-Pareil brick 4″ thick and faced with $^1/_4''$ steel plate was inserted into the front end of the muffle. The retorts were centrally located in the remaining free space. This heating arrangement gave practically identical results on all 8 specimens when the 4 retorts were packed with the same carburizing agent. If the plug were not used, the specimens toward the front end of the muffle would give decidedly lower values than those toward the back end.

Temperature Measurement and Control. Temperature measurements were made by means of a chromel—alumel couple, connected to a Leeds & Northrup potentiometer controller-recorder. The thermocouple was checked occasionally with a standard thermocouple. After the furnace attained the carburizing temperature, the fluctuations in temperature indicated by the recorder were usually not over 5° F. (3° C.).

Carburizing Treatment. The furnace was heated to 1750° F. and allowed to operate at this temperature for at least 15 minutes. The charged retorts were quickly inserted, and allowed to heat to 1750° F. (954° C.) with the maximum current flowing through the furnace. Approximately 30 minutes were required for the recorder to regain the 1750° F. (954° C.) indication, whereupon the heating current was cut down in order to secure closer temperature regulation. At the end of four hours *total time in the furnace*, the retorts were removed and air cooled.

Treatment of Specimens After Carburization. After the retorts were completely cooled, they were opened and emptied of their contents. Note was made of any peculiarities of the carburizing compounds, and the specimens were carefully inspected for signs of attack, adherence of compound, presence of reduced metal, etc. The specimens were washed twice in 95% ethyl alcohol, dried and weighed. Weight increases were calculated to weight increase per unit area. One specimen from each retort was sawed in half, and the section polished for microscopic examination. Case depth measurements were made by means of a filar micrometer. Total case depth and the depth of the hyper-eutectoid plus eutectoid zones were determined.

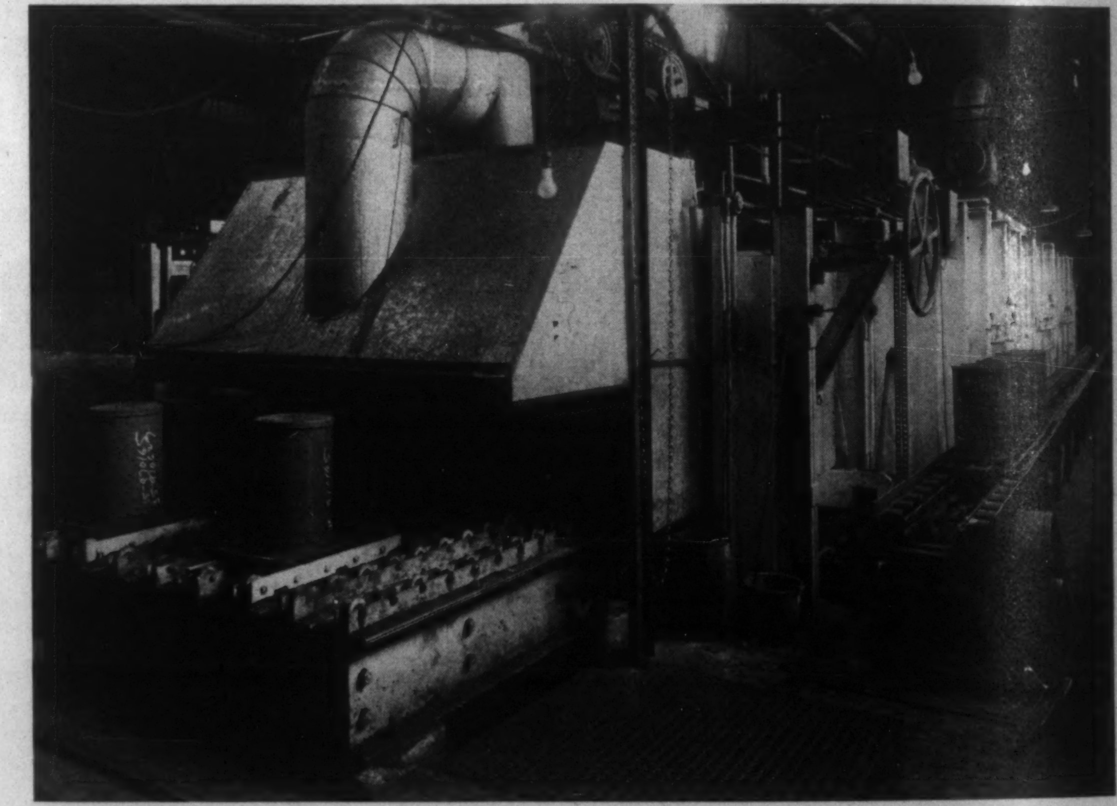
Use of Controls. In every experiment, one retort was packed with a compound which was used as a control. In working with compounds of barium, sodium, potassium and calcium, the respective carbonates were used as controls; with compounds of elements other than the four noted, charcoal with no energizer added was used as the control.

The results obtained are assembled in Tables 1 to 9, according to the periodic classification of the elements. Within a given group, the elements are arranged according to increasing atomic weight.

In order to conserve space, only the average values obtained are included in the tabulation. Each figure for weight increase in grams per square inch represents the average for at least 2 specimens. For case depth data, only one specimen from each retort was sectioned. Measurements were made on the section prepared at 4 positions 90° apart, and the figure given represents the average of these 4 readings. Since charcoal without added energizer and compounds energized with sodium, potassium, calcium and barium carbonate were used as controls, the figures given for these carburizing agents represent the average of several determinations.

When there was no evidence to indicate attack of the steel, the deposition of material on the surfaces of the specimens, or the absorption of material other than carbon by the steel, the weight increases were considered to represent carbon absorbed. In those instances where evidence prompted suspicion that the weight increase did not represent carbon absorbed, the figures are enclosed in parentheses. In such instances, the case depth data must be used as an index of the degree of carburization.

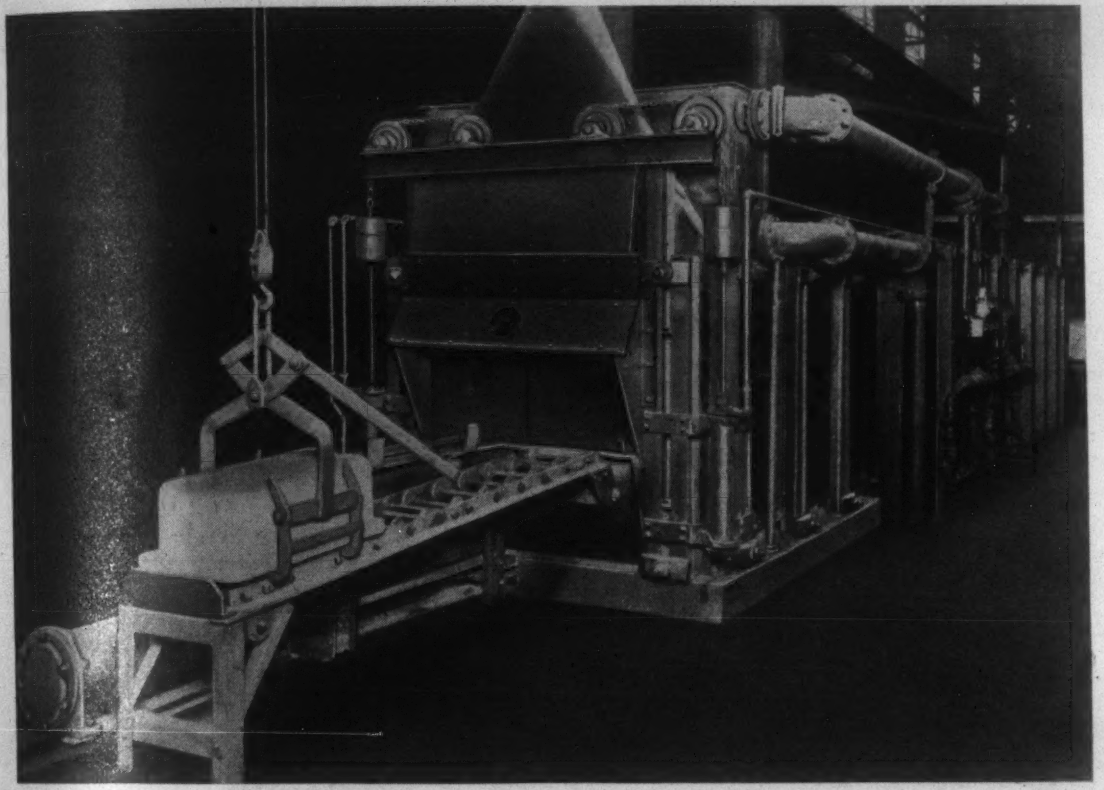
Since the retorts were removed from the furnace and air cooled at the conclusion of the 4-hour carburizing period, the possibility exists that the pro-eutectoid constituents are incompletely precipitated in the carburized region. Should incomplete precipitation occur, it would not affect the figure for total case depth, but would result in high values for the thickness of the hyper-eutectoid plus eutectoid zones. However, even though this condition should hold, it would be of no great importance as all specimens were treated alike



Continuous Gas-fired Counterflow Carburizing Furnace Installed at Brown Lipe Chapin Company. (Courtesy Surface Combustion Corporation.) View Shows Side and Discharge End of Furnace, Boxes and Return Conveyor.

and hence the figures obtained would still serve as an index of the carbon absorbed. It may be mentioned that approximately 10 minutes were required for the retorts to cool from 1750° F. (954° C.) to a black heat, hence it is believed that the precipitation of the pro-eutectoid constituents is quite complete.

In analyzing the data given in Tables 1–9, it should be remembered that the temperature was 1750° F. (954° C.), the total time 4 hours, and the proportions of the mix such that a 25 to 1 ratio existed between the weight of charcoal and the weight of the element whose compound was under consideration. The values given in Table 9 for charcoal alone with no energizing chemicals added should be kept in mind in reviewing the data for the various chemicals.



Continuous Carburizing Furnace Installed at Logan Gear Company. (Courtesy Surface Combustion Corporation.) View Shows Charging End.

Since the objective of this work was to obtain quantitative data on the energizing action of various chemicals, it will be desirable to consider the accuracy of the results. The 2 specimens in a given retort almost without exception gave excellent checks. However, the overall accuracy of the experimental method should be judged by the considerable number of independent determinations made with the carburizing agents which were used as controls. The following tabulation compiled for the three carburizing agents used most frequently for controls indicates the accuracy of the data. The figures in parentheses indicate the number of runs used as a basis.

	Average Deviation from the Mean, Percent		
		Case Depth	
Energizer	Weight Increase	Total	Eutectoid + Hyper-eutectoid
None	5.6% (70)	5.7% (68)	
Na_2CO_3	1.8 (17)	3.8 (17)	2.8% (17)
$BaCO_3$	2.1 (16)	4.2 (16)	3.4 (16)

A detailed discussion of the data for each element is unnecessary, as the nature of the results is evident from an inspection of the tabulated data. However, it will be of interest to point out some of the more important deductions that may be drawn.

Numerous compounds of sodium, potassium, barium and calcium were tried with the object of determining how they compared in activity with the respective carbonates. The interesting observation was made that comparable results were obtained with certain compounds of a given element. Sodium carbonate, bicarbonate, hydroxide, acetate, oxalate, cyanide, chromate and tungstate all gave approximately the same result. Potassium carbonate, bicarbonate, hydroxide, acetate, oxalate, tetroxalate, cyanide, ferricyanide, ferrocyanide, chromate, dichromate and permanganate were approximately of the same activity. Barium carbonate, oxide, hydroxide, acetate and nitrate yielded similar results. In these instances, therefore, it appears that the energizing power of the compound is primarily determined by the metallic part (sodium, potassium or barium for the compounds cited) rather than by the negative radical. However, it is also apparent from the data that compounds other than those mentioned showed a decreased activity with respect to the carbonate, which indicates that in those instances the radical combined with the metal exerted an inhibiting effect upon the energizing action the metallic part of the compound tended to exert.

The results obtained with the calcium compounds indicate that they all are practically inert. The negative result obtained with calcium carbonate is of particular interest, since calcium carbonate is used in commercial case hardening compounds. It appears to serve no useful purpose. The argument may be advanced that calcium carbonate plays the role of a catalytic promoter, that is, though it is inert in itself, it can intensify the energizing action of barium carbonate or sodium carbonate. However, experiments were carried out in which additions of calcium carbonate were made to compounds energized with sodium carbonate or barium carbonate, and no increase in the activity of the compound could be observed.

The claims made in certain patents on carburizing compounds do not appear to be substantiated by the experimental results. In one patent it is claimed that organic salts exert a dual role, the decomposition products of the organic radical supplementing the energizing action of the metallic oxide. The data for oxalates and acetates of calcium, barium, sodium and potassium do not show any definite increase in activity over that of the carbonates of these same metals. Another patent covers the use of magnesium oxide or compounds capable of decomposing into magnesium oxide on heating. The experimental results indicate that magnesium compounds are inert. A third patent covers the use of phosphates. While sodium and potassium phosphates do produce a decided energizing action, they are not as effective as the corresponding carbonates.

Quite a number of sodium, potassium, barium and calcium compounds having a second metal present were tried. None was found to have a distinctly greater activity than the corresponding alkali or alkaline earth carbonate. Some of the double compounds equalled the activity of the corresponding alkali or alkaline earth carbonate, but in many instances the presence of the second metal greatly reduced the activity. This seems to indicate that whatever energizing power is exhibited by compounds containing two metals is due to the sodium, potassium or barium that they contain. The second metal appears to be inert, and often exerts an inhibiting influence.

Continued on page 296

Table 1.—Compounds of Elements of Group I

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
Li	Carbonate	Li_2CO_3	17.55	(0.0525)	0.066	0.027	Hyper-eutectoid	Adherent deposit on specimens.
Na	Carbonate	Na_2CO_3	8.45	0.0400	0.064	0.030	Hyper-eutectoid	
	Bicarbonate	$NaHCO_3$	12.74	0.0412	0.064	0.031	Hyper-eutectoid	
	Hydroxide	$NaOH + Na_2CO_3 + Aq.$	6.66	0.0412	0.064	0.030	Hyper-eutectoid	The sodium hydroxide was analyzed.
	Acetate	$NaC_2H_3O_2 + 3H_2O$	19.14	0.0394	0.068	0.030	Hyper-eutectoid	
	Oxalate	$Na_2C_2O_4$	10.43	0.0388	0.065	0.032	Hyper-eutectoid	
	Cyanide	$NaCN$	8.24	0.0403	0.057	0.031	Hyper-eutectoid	The sodium cyanide contained 95% NaCN.
	Phosphate	$Na_3PO_4 + 12H_2O$	18.04	0.0363	0.061	0.028	Hyper-eutectoid	
	Chloride	$NaCl$	9.22	0.0347	0.059	0.024	Hyper-eutectoid	
	Fluoride	NaF	6.80	0.0292	0.054	0.021	Eutectoid	
	Sulphate	Na_2SO_4	11.00	(0.0133) Loss	0.000		No carbon absorbed	Specimens were severely attacked.
	Thiosulphate	$Na_2S_2O_3 + 5H_2O$	17.76	(0.0377) Loss	0.000		No carbon absorbed	Specimens were severely attacked.
	Chromate	$Na_2CrO_4 + 10H_2O$	22.97	0.0416	0.066	0.030	Hyper-eutectoid	
	Borax	$Na_2B_4O_7 + 10H_2O$	24.93	0.0241	0.048	0.018	Eutectoid	
	Cryolite	Na_3AlF_6	10.80	0.0146	0.036		Hypo-eutectoid	The cryolite used was a natural mineral. It was assumed to contain 100% Na_3AlF_6.
	Bismuthate	$NaBiO_3$	39.30	(0.0109)	0.000		No carbon absorbed	The sodium bismuthate contained 75.2% $NaBiO_3$. The steel was covered with bismuth.
	Stannate	Na_2SnO_3	25.85	(0.0151)	0.032		Hypo-eutectoid	The sodium stannate contained 53% Na_2SnO_3. No coating of tin was apparent from visual examination. However, it is probable that some tin was absorbed by the steel.
	Tungstate	$Na_2WO_4 + 2H_2O$	22.30	(0.0620)	0.066	0.032	Hyper-eutectoid	The steel surfaces had much material adhering to them after carburization.
	Arsenate	$Na_2HAsO_4 + 7H_2O$	21.35	(0.0662)	0.054	0.026	Hyper-eutectoid	A heavy coat of metallic arsenic covered the specimens. However, despite this coating, considerable carbon was absorbed by the steel.
K	Carbonate	K_2CO_3	6.60	0.0348	0.062	0.025	Hyper-eutectoid	
	Bicarbonate	$KHCO_3$	9.28	0.0353	0.061	0.025	Hyper-eutectoid	
	Hydroxide	$KOH + K_2CO_3 + Aq.$	6.22	0.0342	0.064	0.023	Hyper-eutectoid	The potassium hydroxide was analyzed.
	Acetate	$KC_2H_3O_2$	9.12	0.0321	0.061	0.022	Hyper-eutectoid	
	Oxalate	$K_2C_2O_4 + H_2O$	8.62	0.0364	0.063	0.027	Hyper-eutectoid	
	Tetroxalate	$KHC_2O_4 \cdot H_2C_2O_4 + 2H_2O$	20.65	0.0332	0.061	0.023	Hyper-eutectoid	
	Cyanide	KCN	6.25	0.0371	0.057	0.027	Hyper-eutectoid	
	Sulphocyanate	$KSCN$	9.04	(0.0789)	0.038		Hypo-eutectoid	The specimens were badly attacked. Nevertheless, some carbon was absorbed.
	Ferrocyanide	$K_4Fe(CN)_6 + 3H_2O$	9.75	0.0349	0.056	0.026	Hyper-eutectoid	
	Ferricyanide	$K_3Fe(CN)_6$	10.10	0.0350	0.060	0.029	Hyper-eutectoid	
	Phosphate	K_3PO_4	6.76	0.0279	0.047	0.018	Eutectoid	
	Chloride	KCl	7.08	0.0297	0.053	0.019	Hyper-eutectoid	
	Sulphate	K_2SO_4	8.19	(0.0398)	0.000		No carbon absorbed	The specimens were badly attacked.
	Chromate	K_2CrO_4	9.04	0.0333	0.064	0.025	Hyper-eutectoid	
	Dichromate	$K_2Cr_2O_7$	13.08	0.0324	0.059	0.024	Hyper-eutectoid	
	Permanganate	$KMnO_4$	13.93	0.0327	0.058	0.023	Hyper-eutectoid	
	Silico-fluoride	K_2SiF_6	10.12	0.0127	0.032		Hypo-eutectoid	
Cu	Oxide	CuO	4.77	0.0191	0.046		Hypo-eutectoid	No coating of copper was apparent from visual examination.
	Basic carbonate	$CuCO_3 \cdot Cu(OH)_2$	6.50	0.0193	0.052		Hypo-eutectoid	The formula given is approximate. No coating of copper was apparent from visual examination.
Ag	Oxide	Ag_2O	4.12	0.0206	0.046		Hypo-eutectoid	No coating of silver was apparent from visual examination.
	Nitrate	$AgNO_3$	5.93	0.0248	0.060	0.016	Eutectoid	No coating of silver was apparent from visual examination.

Table 2.—Compounds of Elements of Group II

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
Be	Beryl	$(SiO_3)_6Al_2Be_3$	44.3	0.0141	0.042		Hypo-eutectoid	The beryl used was a natural mineral.
Mg	Oxide	MgO	6.23	0.0188	0.057		Hypo-eutectoid	
	Carbonate	$(MgCO_3)_4 \cdot Mg(OH)_2 + 5H_2O$	13.80	0.0161	0.049		Hypo-eutectoid	The formula given is approximate.
Ca	Carbonate	$CaCO_3$	9.09	0.0189	0.049		Hypo-eutectoid	
	Oxide	CaO	5.30	0.0178	0.050		Hypo-eutectoid	
	Hydroxide	$Ca(OH)_2$	6.89	0.0169	0.046		Hypo-eutectoid	
	Acetate	$Ca(C_2H_3O_2)_2$	13.66	0.0186	0.048		Hypo-eutectoid	
	Oxalate	$CaC_2O_4 + H_2O$	12.75	0.0191	0.052		Hypo-eutectoid	
	Nitrate	$Ca(NO_3)_2 + 4H_2O$	19.08	0.0194	0.060		Hypo-eutectoid	
	Phosphate	$Ca_3(PO_4)_2$	9.35	0.0151	0.047		Hypo-eutectoid	
	Chloride	$CaCl_2 + 6H_2O$	17.94	0.0219	0.054	0.017	Eutectoid	
	Carbide	CaC_2	6.02	0.0196	0.049		Hypo-eutectoid	Commercial calcium carbide was used. Fresh lumps were selected and it was assumed the material was 100% CaC_2.
	Sulphate	$CaSO_4 + 2H_2O$	14.69	0.0181	0.045		Hypo-eutectoid	
	Chromate	$CaCrO_4 + 2H_2O$	16.11	0.0166	0.049		Hypo-eutectoid	
Zn	Oxide	ZnO	4.74	(0.0197)	0.049		Hypo-eutectoid	No coating of zinc was apparent from visual examination. However, it is probable that some zinc was absorbed by the steel.
	Basic carbonate	Variable	6.83	(0.0198)	0.048		Hypo-eutectoid	The basic zinc carbonate contained 68% ZnO. No coating of zinc was apparent from visual examination. However, it is probable that some zinc was absorbed by the steel.
Sr	Carbonate	$SrCO_3$	6.30	0.0381	0.064	0.029	Hyper-eutectoid	
	Chloride	$SrCl_2 + 6H_2O$	10.83	0.0286	0.056	0.022	Hyper-eutectoid	
	Fluoride	SrF_2	5.43	0.0277	0.052	0.021	Eutectoid	
Cd	Carbonate	$CdCO_3$	5.78	0.0181	0.048		Hypo-eutectoid	No coating of cadmium was apparent from visual examination.
Ba	Carbonate	$BaCO_3$	5.44	0.0382	0.062	0.030	Hyper-eutectoid	
	Oxide	BaO	4.28	0.0382	0.061	0.031	Hyper-eutectoid	
	Hydroxide	$Ba(OH)_2 + 8H_2O$	8.41	0.0368	0.060	0.031	Hyper-eutectoid	
	Acetate	$Ba(C_2H_3O_2)_2 + H_2O$	7.36	0.0393	0.064	0.031	Hyper-eutectoid	
	Nitrate	$Ba(NO_3)_2$	7.07	0.0380	0.060	0.031	Hyper-eutectoid	
	Chloride	$BaCl_2 + 2H_2O$	6.65	0.0340	0.058	0.026	Hyper-eutectoid	
	Carbide	BaC_2	4.49	0.0254	0.055	0.017	Eutectoid	Fresh lumps of barium carbide were selected They were assumed to be 100% BaC_2.
	Sulphide	BaS	4.70	0.0292	0.060	0.024	Hyper-eutectoid	
	Sulphate	$BaSO_4$	6.35	0.0297	0.053	0.023	Hyper-eutectoid	
	Chromate	$BaCrO_4$	6.86	0.0292	0.056	0.023	Hyper-eutectoid	

Table 3.—Compounds of Elements of Group III

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
B	Boric acid	H_3BO_3	18.60	(0.0115)	0.031		Hypo-eutectoid	Steel seemed to be slightly attacked.
	Borax	$Na_2B_4O_7 + 10H_2O$	26.05	(0.0225)	0.050	0.012	Eutectoid	Steel seemed to be slightly attacked.
Al	Oxide	Al_2O_3	7.05	0.0160	0.050		Hypo-eutectoid	
	Hydroxide	$Al(OH)_3$	10.38	0.0162	0.050		Hypo-eutectoid	

Table 4.—Compounds of Elements of Group IV

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
Si	Dioxide	SiO_2	7.89	0.0137	0.046		Hypo-eutectoid	
	Potassium silicofluoride	K_2SiF_6	23.90	(0.0261)	0.037		Hypo-eutectoid	The specimens were badly attacked. Nevertheless, some carbon was absorbed.
Ti	Dioxide	TiO_2	6.24	0.0154	0.044		Hypo-eutectoid	
Zr	Zircon	$ZrSiO_4$	7.44	0.0190	0.052		Hypo-eutectoid	The zircon used was a natural mineral. It was assumed to be 100% $ZrSiO_4$.
Sn	Oxide	SnO_2	4.84	(0.0081)	0.000		No carbon absorbed	No coating of tin was apparent from visual examination. However, since microscopic examination showed that no carbon was absorbed, the weight increase must be due to a slight deposit of tin.
	Sodium stannate	Na_2SnO_3	11.89	(0.0117)	0.032		Hypo-eutectoid	The sodium stannate contained 53% Na_2SnO_3. No coating of tin was apparent from visual examination. However, the result with SnO_2 indicates that a slight deposit of tin is probably formed on the steel.
Pb	Litharge	PbO	4.14	(0.0124)	0.038		Hypo-eutectoid	A slight deposit of lead was formed on the steel surfaces.
	Basic carbonate	$2PbCO_3{\cdot}Pb(OH)_2$	6.97	(0.0118)	0.031		Hypo-eutectoid	A slight deposit of lead was formed on the steel surfaces.

Table 5.—Compounds of Elements of Group V

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
As	Trioxide	As_2O_3	5.02	(0.0197)	0.029		Hypo-eutectoid	The specimens were coated with arsenic. However, despite this coating, considerable carbon was absorbed.
	Sodium arsenate	$Na_2HAsO_4 + 7H_2O$	14.30	(0.0443)	0.049	0.014	Eutectoid	The specimens were coated with arsenic. However, despite this coating, considerable carbon was absorbed.
Sb	Trioxide	Sb_2O_3	4.53	(0.0861)	0.000		No carbon absorbed	The specimens were coated with antimony. No carbon was absorbed.
Bi	Trioxide	Bi_2O_3	4.26	(0.0258)	0.000		No carbon absorbed	The specimens were coated with bismuth. No carbon was absorbed.
	Hydroxide	$Bi(OH)_3$	4.74	(0.0245)	0.000		No carbon absorbed	The specimens were coated with bismuth. No carbon was absorbed.
	Subcarbonate	$2(BiO)_2CO_3{\cdot}H_2O$	4.72	(0.0222)	0.000		No carbon absorbed	The specimens were coated with bismuth. No carbon was absorbed.
	Sodium bismuthate	$NaBiO_3$	6.65	(0.0103)	0.000		No carbon absorbed	The sodium bismuthate contained 75.2% $NaBiO_3$. The specimens were covered with bismuth. No carbon was absorbed.

Table 6.—Compounds of Elements of Group VI

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
Cr	Oxide	Cr_2O_3	5.52	0.0170	0.054		Hypo-eutectoid	
	Hydroxide	$Cr(OH)_3$	7.34	0.0167	0.046		Hypo-eutectoid	
	Basic carbonate	$Cr_2O(CO_3)_2$	8.46	0.0237	0.049	0.012	Eutectoid	
	Sodium chromate	$Na_2CrO_4 + 10H_2O$	20.83	0.0377	0.066	0.028	Hyper-eutectoid	
	Potassium chromate	K_2CrO_4	13.00	0.0343	0.061	0.024	Hyper-eutectoid	
	Potassium dichromate	$K_2Cr_2O_7$	10.18	0.0321	0.060	0.022	Hyper-eutectoid	
	Calcium chromate	$CaCrO_4 + 2H_2O$	12.90	0.0174	0.049		Hypo-eutectoid	
	Barium chromate	$BaCrO_4$	16.31	0.0372	0.063	0.028	Hyper-eutectoid	
Mo	Molybdic acid	MoO_3	6.59	0.0311	0.057	0.023	Hyper-eutectoid	The molybdic acid contained 85% MoO_3.
	Ammonium molybdate	$(NH_4)_6Mo_7O_{24} + 4H_2O$	6.84	0.0317	0.059	0.023	Hyper-eutectoid	
W	Tungstic acid	$H_2WO_4{\cdot}WO_3$	4.98	0.0224	0.057	0.017	Eutectoid	
	Sodium tungstate	$Na_2WO_4 + 2H_2O$	6.71	0.0327	0.059	0.024	Hyper-eutectoid	
U	Nitrate	$UO_2(NO_3)_2 + 6H_2O$	7.77	0.0204	0.057	0.011	Eutectoid	
	Acetate	$UO_2(C_2H_3O_2)_2 + 2H_2O$	6.64	0.0199	0.057	0.009	Eutectoid	
	Sodium uranate	$Na_2U_2O_7 + 6H_2O$	5.86	0.0160	0.042		Hypo-eutectoid	

Table 7.—Compounds of Elements of Group VII

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
Mn	Dioxide	MnO_2	5.95	0.0229	0.050	0.013	Eutectoid	
	Hydroxide	$Mn_2O_2(OH)_2$	6.02	0.0150	0.046		Hypo-eutectoid	
	Carbonate	$MnCO_3$	7.73	0.0202	0.052		Hypo-eutectoid	
	Potassium permanganate	$KMnO_4$	10.32	0.0320	0.063	0.023	Hyper-eutectoid	

Table 8.—Compounds of Elements of Group VIII

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.^{2}	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper-Eutectoid		
Fe	Oxide	Fe_2O_3	5.42	0.0252	0.052	0.015	Eutectoid	
	Carbonate	$FeCO_3$	7.67	0.0258	0.054	0.016	Eutectoid	
	Potassium ferrocyanide	$K_4Fe(CN)_6 + 3H_2O$	23.20	0.0394	0.066	0.029	Hyper-eutectoid	
	Potassium ferricyanide	$K_3Fe(CN)_6$	19.10	0.0362	0.058	0.028	Hyper-eutectoid	
Ni	Oxide	Ni_2O_3	5.34	0.0228	0.050	0.008	Eutectoid	
	Basic carbonate	$2NiCO_3{\cdot}3Ni(OH)_2 + 4H_2O$	7.42	0.0288	0.057	0.022	Hyper-eutectoid	
Co	Oxide	Co_2O_3	5.34	0.0219	0.046	0.013	Eutectoid	
	Carbonate	$CoCO_3$	7.54	0.0260	0.058	0.015	Eutectoid	
	Nitrate	$Co(NO_3)_2 + 6H_2O$	16.51	0.0290	0.057	0.020	Eutectoid	

Table 9.—Miscellaneous

Element	Compound	Formula	% Chemical in Carburizing Agent	Wt. Increase g./in.[2]	Case Depth, Inches		Character of Case at Outer Edges	Remarks
					Total	Eutectoid + Hyper Eutectoid		
	Charcoal, with no chemical added		None	0.0192	0.050		Hypo-eutectoid. Approaches eutectoid composition quite closely	Figures are averages for 70 runs.
NH_4	Ammonium carbonate	Variable	10.00	0.0217	0.051		Hypo-eutectoid	Due to the extremely variable composition of ammonium carbonate, the carburizing agent was arbitrarily made up by mixing 10% by weight of the carbonate with 90% of charcoal.
	Ammonium bicarbonate	NH_4HCO_3	14.90	0.0208	0.052		Hypo-eutectoid	The ammonium radical was considered as the metallic component of the bicarbonate. The carburizing agent was prepared so that the weight ratio of charcoal to ammonium radical was 25/1.
	Ammonium chloride	NH_4Cl	10.61	(0.0107)	0.052		Hypo-eutectoid	The ammonium radical was considered as the metallic component of the chloride. The carburizing agent was prepared so that the weight ratio of charcoal to ammonium radical was 25/1. The steel was attacked.
	Monazite sand	Variable	10.00	0.0195	0.051		Hypo-eutectoid	The sand is a naturally occurring mixture of rare earth oxides. Due to its variable composition, the carburizing agent was arbitrarily made up by mixing 10% by weight of the sand with 90% of charcoal.

Certain compounds not containing alkali or alkaline earth metals were found to exert distinct energizing effects, but they did not produce effects comparable in magnitude to those produced by the active compounds of sodium, potassium or barium. The tabulated data show that certain compounds of chromium, molybdenum, tungsten, manganese, iron, nickel and cobalt exerted an energizing action, even when no alkali or alkaline earth metals were in combination with them.

It will be of interest to consider the inhibiting effect of certain compounds. Stannic oxide, SnO_2, prevented carbon absorption entirely, and left the surface of the steel in excellent condition. While there was some deposition of tin as indicated by the weight increase, it was small and was not apparent from visual examination of the steel surfaces. Bismuth and antimony compounds completely prevented carbon absorption, but the steel surfaces were covered with considerable reduced metal. Lead compounds inhibited carburization, though they did not completely prevent carbon absorption. This indicates that cutting lubricants containing white lead may cause irregular carburization if the steel is not thoroughly cleaned.

Arsenic compounds, it is interesting to note, acted differently than bismuth and antimony. The reduced arsenic was not capable of preventing carbon absorption. In fact, when sodium arsenate was used, eutectoid or hyper-eutectoid cases could be obtained despite a heavy coat of reduced arsenic on the steel.

In the preparation of case hardening compounds, there appears to be no particular reason for using any energizing materials other than the cheap and highly active carbonates of sodium and barium. The experimental data appear to indicate that the use of calcium carbonate is not warranted. It is also apparent that complex mixes are of questionable merit.

The experimental results raise some doubts about the explanation of energizer action frequently given in various texts and in articles in technical journals. It is stated that the carbonate dissociates into metallic oxide and carbon dioxide. The latter immediately reacts with the incandescent carbon to form carbon monoxide, and the acceleration in the rate of carburization is said to be due to the resulting increased concentration of carbon monoxide in the gaseous phase. That this simple theory is inadequate, is indicated by the following facts brought out by the experimental data. Certain carbonates which dissociate into metallic oxide and carbon dioxide very readily are absolutely inert as energizers. For example, calcium and magnesium carbonates are entirely without effect despite the fact that carbon dioxide is readily evolved from them on heating. The similar results yielded by sodium carbonate, bicarbonate and hydroxide, by potassium carbonate, bicarbonate and hydroxide, and by barium carbonate, oxide and hydroxide suggest that the energizing power is primarily determined by the metallic part of the compound rather than by its carbon dioxide content.

The writers wish to express their appreciation of the assistance rendered by Messrs. M. J. Sterba, G. C. Williams and G. B. Zimmerman in the performance of the experimental work.

---

[1] Takahashi. *Science Reports Tohoku Imperial University*, Vol. 17, 1928, page 883.

[2] Hebler. *Chemiker Zeitung*, Vol. 52, 1928, page 775.

[3] Rodman. *Transactions American Society for Steel Treating*, Vol. 7, 1925, page 635.

[4] Shepherd. *Transactions American Society for Steel Treating*, Vol. 6, 1924, page 606.

[5] Fetchenko-Tschopiwskij. *Revue de la Société russe de Métallurgie*, Vol. 1, 1914, pages 245, 480; *Revue de Métallurgie*, Vol. 12, 1915, page 518 (abstract); Vol. 14, 1917, page 90 (abstract).

◆ ◆ ◆

MAGNESIUM METAL PRICES AGAIN REDUCED

Substantially reduced prices on magnesium metal have been announced by The Dow Chemical Company, Midland, Michigan. The new prices are 30¢ per pound in carload lots and 32¢ per pound in less than carload lots. This last reduction climaxes a period of 16 years of successful manufacturing experience of this metal by this company. During this time, by means of process refinements through extensive research, production costs have been consistently reduced. The average price for magnesium metal for 1915 as reported by the Bureau of Mines was $5.00 per pound. The newly announced price of 30¢ per pound in carload lots represents a remarkable production record that should instill confidence in those considering the use of or are now employing magnesium alloys.

Paralleling this progress in reducing production costs are equal advances made in fabrication methods in foundry and shop. Dowmetal (the trade name that identifies the magnesium alloys produced by The Dow Chemical Company) can be fabricated into many difficult shapes and forms. It can be readily cast, rolled, drawn, forged, extruded, welded and machined by methods similar to those in use in metal working industries. Because magnesium alloys are the lightest of all engineering metals commercially available, one-third lighter than aluminum and only one-fourth as heavy as iron or steel and are the easiest of all metals to machine, they are destined to serve industry in innumerable ways.

Contrary to the opinion of many, magnesium is one of the most plentiful metals in the earth's crust. Potential production facilities are ample to satisfy almost any demand. Now that magnesium metal is available in commercial quantities and at commercial prices, serious consideration will be given to its adaptation in many lines of industry.

The Lead-Zinc Eutectic

BY J. M. HODGE* AND R. H. HEYER*

IT IS odd that all details of the equilibrium diagram of two of our common, and cheapest metals, lead and zinc, have remained in doubt. Both melt low enough so that their study does not involve some of the difficulties encountered in the study of the more refractory metals.

Revisions, such as this, of the diagrams for common metals make us realize how little we really know about the metals in daily use, to say nothing of all that is to be found out about the more uncommon ones.

THE object of the work was to determine the composition of the lead-rich eutectic of the system. The results are based primarily on thermal and microscopical analysis.

In the course of the work rather good evidence was found that a slight amount of zinc is soluble in lead in the solid state.

The eutectic composition as found in this investigation is 0.50% Zn–99.50 Pb by weight. The eutectic temperature is 318.2° C. The solubility of zinc in lead in the solid state is about 0.05% Zn at the eutectic temperature.

Heycock and Neville[1] in 1892 found the eutectic composition to be about 2.3 mol % Zn, or 0.74% Zn. This value was determined thermally by the use of mercurial thermometers and agrees much better with the results of this investigation than the value of 1.2% Zn given by Arnemann[2] in 1910 or 2.3% Zn as given by Peirce[3] in his recent diagram.

Many preliminary thermal analyses, using various methods, showed that an ordinary inverse rate curve taken from a large mass of alloy was unsuited to this determination. The poor heat conductivity of the alloys made it difficult to maintain a uniform temperature within a large body of alloy while cooling. This caused the outer portion of the melt to freeze before the inner and prevented sharp heat effects being indicated by the thermocouple. On using a small annular ring of melt with the thermocouple centrally located, it was found desirable to use a differential couple to indicate the small variations of temperature at the liquidus. Using a 30 g. sample a simple thermocouple of the differential type was fairly satisfactory.

The final apparatus as used in these tests is shown in Fig. 1. It is essentially an aluminum crucible holding 11 g. of alloy. It contains a base metal differential thermocouple made up of 3 sets of opposed junction in series, one junction of each set being in the lower aluminum neutral body and the other near the geometric center of the melt. The hot junction of a simple base metal thermocouple is also located at the geometric center on the melt. A moving coil, reflecting galvanometer of 0.97 mm. per mv. sensitivity, 38 ohms resistance, 12.2 seconds period, and placed 42 inches from the ground glass scale was used in the differential circuit. It gave deflections of several centimeters at both the liquidus and solidus breaks. A Leeds & Northrup potentiometer indicator was used in the simple thermocouple circuit.

Fig. 2 shows the arrangement of the aluminum crucible within a large pyrex glass tube sealed at the bottom and stoppered at the top. The tube and contents were heated in an electric resistance furnace wound so that the region around the crucible was uniformly hot while the top of the furnace was relatively cool. Asbestos fiber packed in the tube directly over the crucible also helped to keep the rubber stopper at the top cool. City gas was run through the tube at a rapid rate during melting and a slight uniform flow maintained while running the thermal analysis. On inspection, the surface of the alloys appeared very free from oxidation when melted and cooled under these conditions.

Most of the microscopic work was done before the thermal analyses were run. Test lead and pure zinc were melted separately, mixed, deoxidized with ammonium chloride, stirred thoroughly with a wood stick, and chill cast in an iron mold. Parts of these ingots were analyzed and the remainder remelted and slowly cooled from slightly over the melting point to room temperature in about 8 hours. The new ingots were split lengthwise, 1/2 being used for microscopic work and the other for chemical analysis. Because of the large segregation due to gravity, especially in the hyper-eutectic alloys, the photomicrographs had to be taken at the same horizontal plane as the chemical analyses.

The thermal analysis specimens were made by melting spectroscopically pure lead, furnished through the courtesy of Mr. Mulligan of the U. S. Smelting Lead Refinery, East Chicago, and pure Mallinckrodt zinc. The metals were melted, mixed and deoxidized as before, and then poured onto a metal plate as chill castings 1/16-to 1/8-inch thick. Some of the photomicrographs were made from remelted and slowly cooled portions of these heats.

The chemical analysis of the alloys was performed as follows:

> After dissolving in 1–3 HNO_3 the lead was removed as $PbSO_4$ by precipitating with 1–1 H_2SO_4 and filtering off the $PbSO_4$. After taking to fumes of SO_3 the solution was made slightly alkaline with ammonia to remove traces of iron and the small amount of lead remaining after the first precipitation. After filtering, the solution was made neutral to methyl orange by titration with HCl and the zinc was precipitated as $ZnNH_4PO_4$, which was filtered in a gooch crucible and ignited to $Zn_2P_2O_7$.

Table 1. Chemical Analysis of All Thermal Analysis Alloys

Identification Analysis	Chemical Analyses		Average Chemical Analysis
Pb			0.000% Zn
0.02% Zn	0.0230	....	0.023
0.05	0.0490	0.0436	0.046
0.06	0.0598	0.0587	0.059
0.09	0.088	....	0.088
0.15	0.149	0.155	0.152
0.24	0.237	0.240	0.238
0.29	0.287	....	0.287
0.38	0.381	0.377	0.379
0.51	0.507	0.519	0.513
0.59	0.591	....	0.591

Due to their extreme softness, these alloys had to be prepared with care to prevent flow of the metal. Samples were cut vertically from the ingots by a sharp, oiled hack saw. They were then ground on numbers 1, 0 and 00 French emery papers using a solution of paraffine in kerosine for a lubricant. They were then cleaned with alcohol and naphtha, and rough polished on felt or broadcloth wheels using a fairly coarse suspension of levigated alumina in distilled water containing a few drops of liquid soap. This polishing was continued until all emery particles were removed from the surface of the metal. This required from fifteen minutes to half an hour or more. A black smudge which first forms must be entirely removed by the end of this process so that the surface has the appearance of a roughly polished piece of steel. After washing, the specimens were finely polished on a silk velvet wheel using a very fine suspension of alumina in a soap solution. Very light polishing pressure had to be used to prevent further smudging. When the scratches were apparently removed the following etch was used:

---

* Purdue University. A part of this work was presented to the University as a graduate thesis by Mr. J. M. Hodge.

[1] C. T. Heycock & F. H. Neville. *Journal of the Chemical Society*, Vol. 61, 1892, page 905.

[2] P. T. Arnemann. *Metallurgie*, Vol. 7, 1910, pages 201–211.

[3] W. M. Pierce. *National Metals Handbook*, 1930 Edition, American Society for Steel Treating, page 818.

Glycerine	60 cc.
Glacial $HC_2H_3O_2$	20 cc.
Concd. HNO_3	20 cc.

This reagent was first used on these alloys by Dr. Bray. It should be made up fresh for best results. Both the specimen and etching reagent must be kept free from water. By repeated polishing and etching the structures of the alloys were brought out as shown in the following photomicrographs.

Figs. 3 to 6 represent each type of structure found in the series. Fig 5 is very likely the nearest to the true eutectic structure. The small size of the sample did not permit an accurate chemical analysis.

Figs. 7 to 14 show an increasing amount of eutectic zinc appearing in the lead grains in the form of plates and possibly some needles. Figs. 8 and 9 show an absence of any zinc plates or needles which indicates that some zinc is in solution. Figs. 14 and 15 are the closest to being completely eutectic of any specimens for which we have adequate chemical analy-

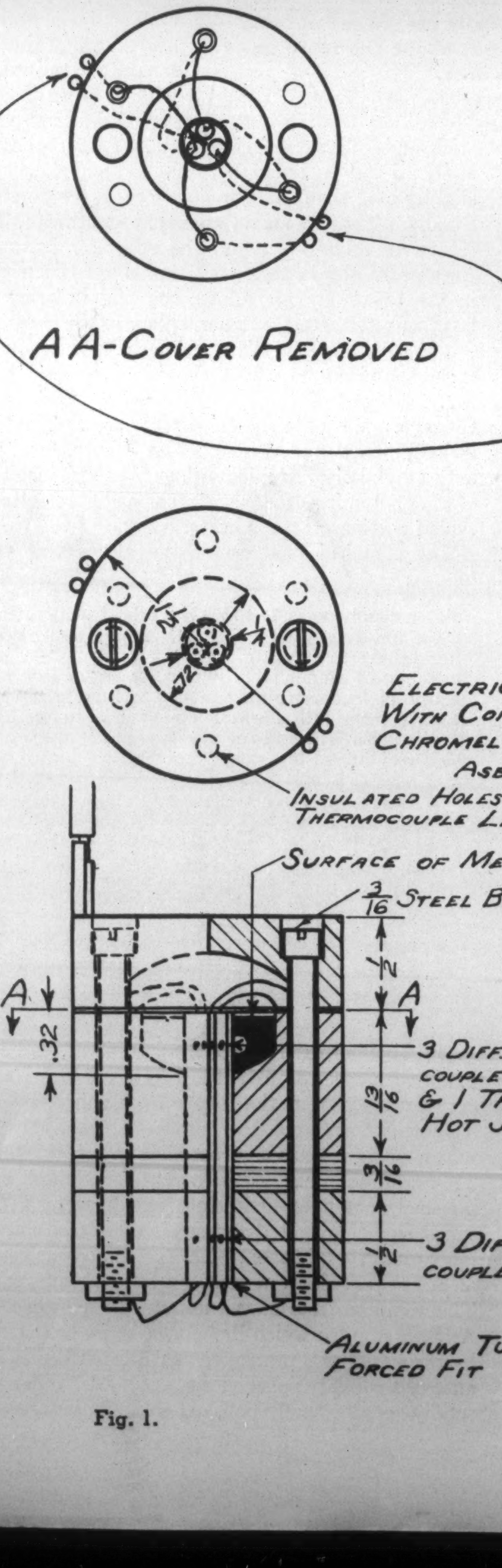

AA-Cover Removed
2½
¼
½
Insulated Holes for Thermocouple Leads
Surface of Melt
3/16 Steel Bolt
A
A
.32
½
13/16
3/16
½
3 Diff. Thermocouple Junctions & 1 Thermocouple Hot Junction
3 Diff. Thermocouple Junctions
Aluminum Tube Forced Fit

Fig. 1.

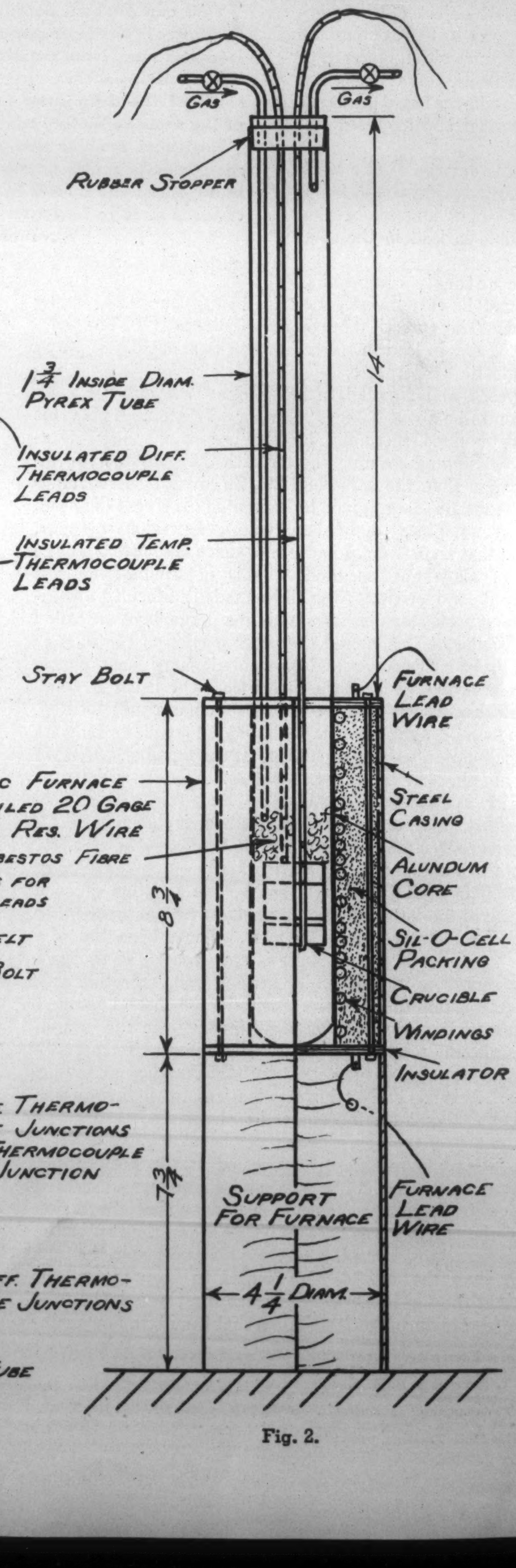

Gas
Gas
Rubber Stopper
14
1¾ Inside Diam. Pyrex Tube
Insulated Diff. Thermocouple Leads
Insulated Temp. Thermocouple Leads
Stay Bolt
Furnace Lead Wire
Electric Furnace With Coiled 20 Gage Chromel Res. Wire
Asbestos Fibre
Steel Casing
Alundum Core
Sil-O-Cell Packing
Crucible
Windings
Insulator
8¾
7¾
Support for Furnace
Furnace Lead Wire
4¼ Diam.

Fig. 2.

TYPES OF LEAD-ZINC STRUCTURES - 66 2/3 X

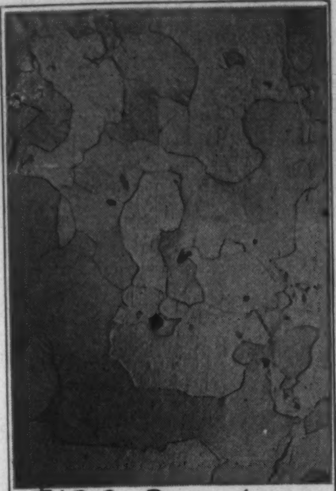


FIG. 3 PURE LEAD

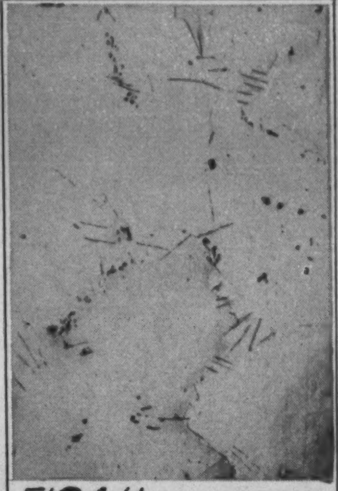


FIG. 4 HYPO-EUTECTIC

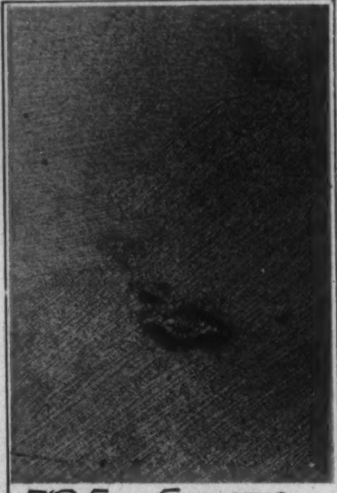


FIG. 5 EUTECTIC

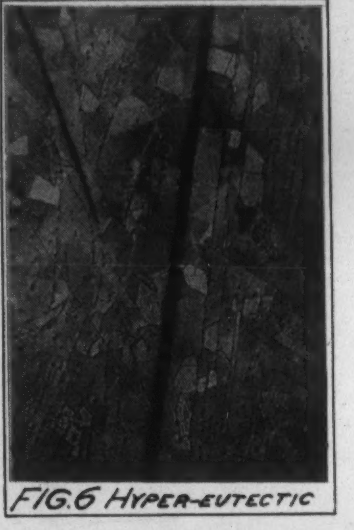


FIG. 6 HYPER-EUTECTIC

LEAD-ZINC SERIES - 66 2/3 X

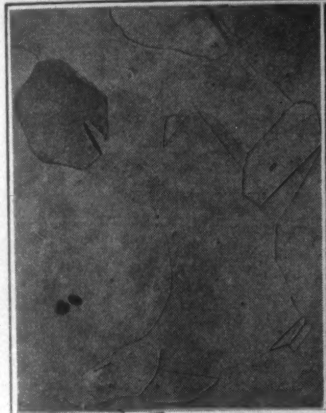


FIG. 7 PURE LEAD

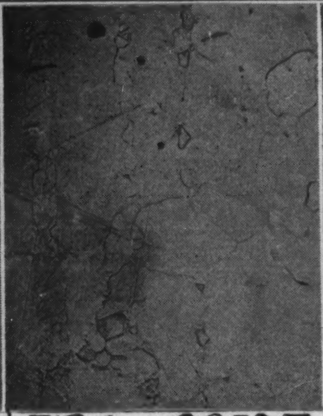


FIG. 8 0.05% Zn

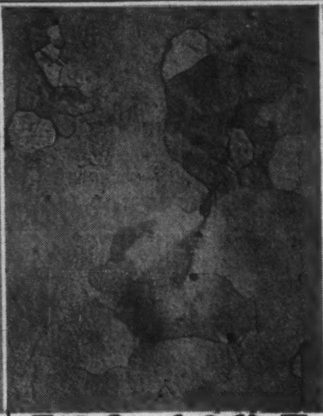


FIG. 9 0.06% Zn

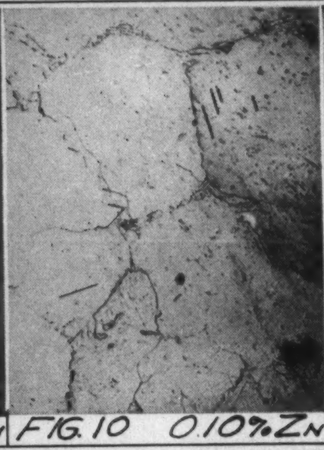


FIG. 10 0.10% Zn

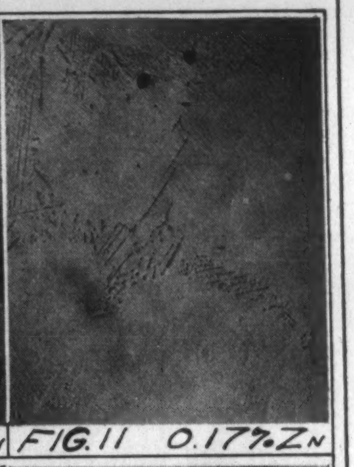


FIG. 11 0.17% Zn

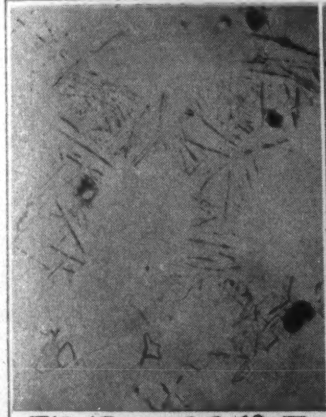


FIG. 12 0.24% Zn

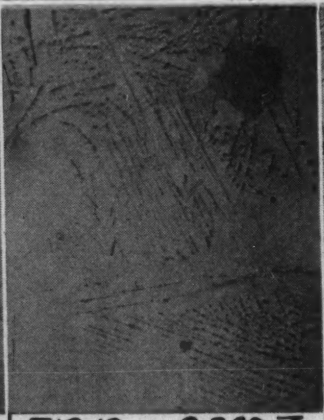


FIG. 13 0.38% Zn

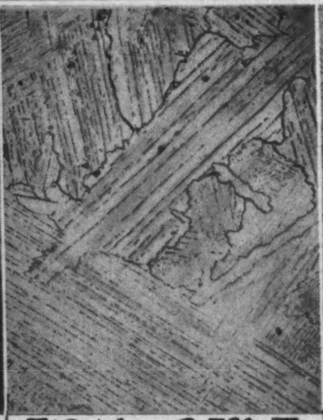


FIG. 14 0.53% Zn

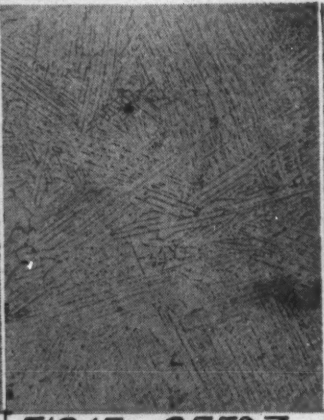


FIG. 15 0.55% Zn

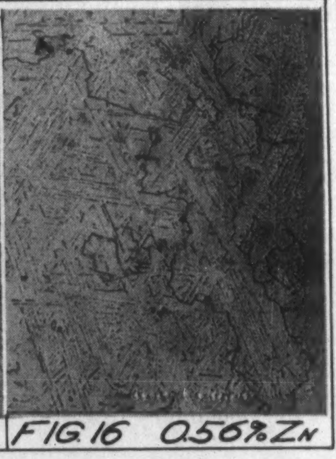


FIG. 16 0.56% Zn

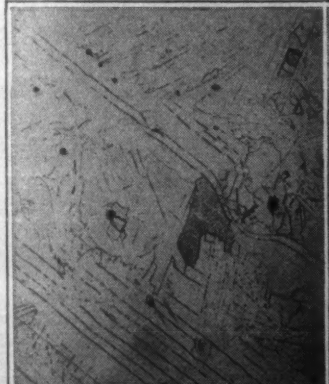


FIG. 17 0.59% Zn

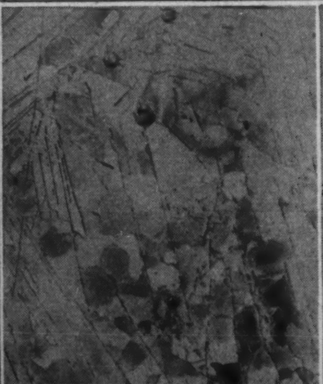


FIG. 18 0.80% Zn

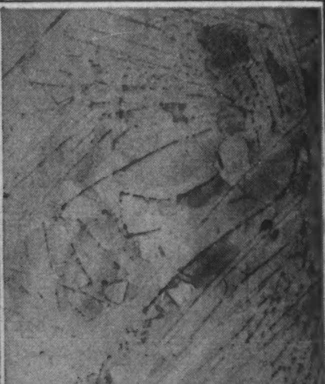


FIG. 19 0.90% Zn

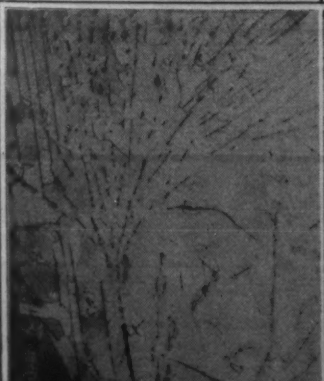


FIG. 20 1.20% Zn

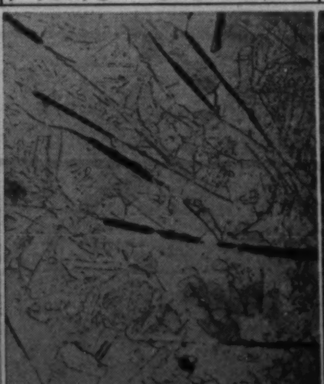


FIG. 21 1.30% Zn

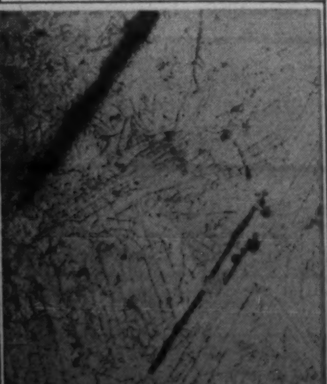


FIG. 22 1.90% Zn

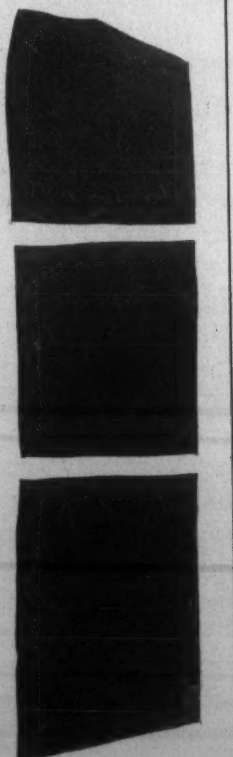


FIG. 23

SLOWLY COOLED INGOT SHOWING SEGREGATION OF ZINC (NEEDLES)

ANALYSIS VARIES FROM 0.80% Zn AT THE BOTTOM TO 1.40% Zn AT TOP

Table 2. Experimental Data for 0.06% Zn Cooling Curve

Minutes	Differential Deflection Centimeters	Temp., Millivolts	Temp., ° C.
0	6.95	13.44	
1	6.85	13.42	
2	6.80	13.41	
4	6.70	13.395	
6	6.65	13.39	
7	6.65	13.37	
8	6.60	13.36	
9	6.90	13.36	327.0°
10	10.00	13.36	
11	11.30	13.36	
12	11.20	13.35	
13	10.50	13.33	
15	9.20	13.32	
17	8.20	13.30	
19	7.65	13.28	
23	6.75	13.24	
28	6.15	13.21	
33	5.75	13.18	
39	5.65	13.14	
43	5.50	13.11	
46	5.40	13.10	
49	5.35	13.09	
55	5.20	13.07	
58	5.15	13.04	
61	5.05	13.02	
64	5.00	13.01	
66	5.00	13.00	
68	5.15	13.00	318.2°
69	5.35	13.00	
70	5.40	13.00	
72	5.15	13.00	
74	5.00	12.99	
76	5.00	12.99	
78	4.90	12.98	
82	4.80	12.96	

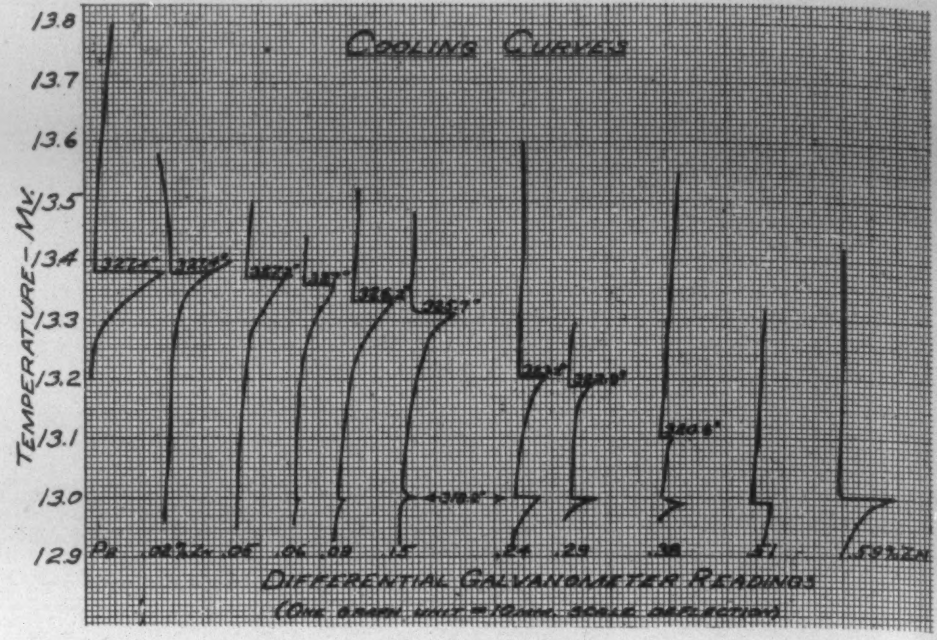


Fig. 24.

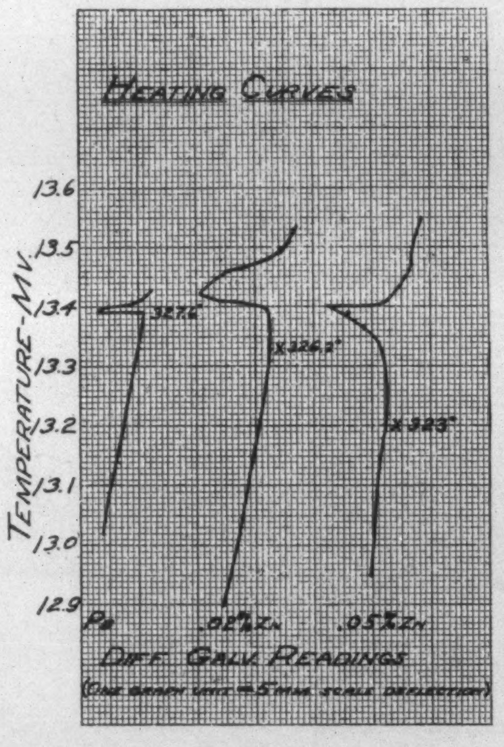


Fig. 25.

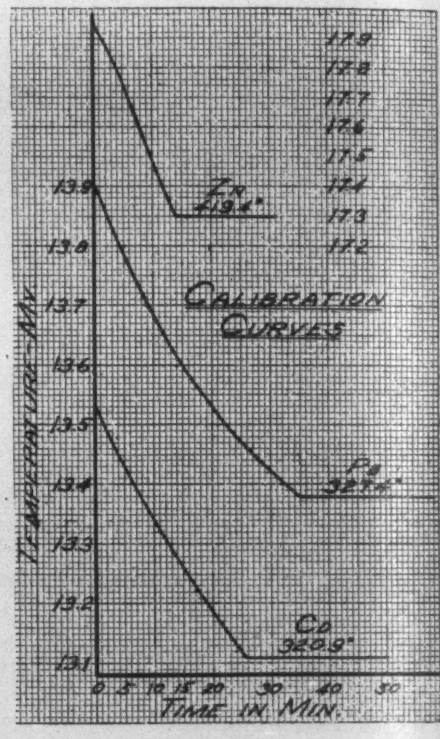


Fig. 26.

sis. It is not unlikely that a specimen analyzing 0.50% Zn would have the same structure thereby checking the thermal data following.

The plates of zinc appear to be in quite equally spaced parallel rows within each hypo-eutectic grain. The zinc plates are composed of hexagonal close-packed cells and evidently form parallel to the atomic planes of the face-centered cubic lead space lattice. Since the photomicrographs are at only 100 × magnification, there must be several thousand rows of lead atoms between each plate of zinc. If the average distance between plates is one millimeter at 100×, about 20,000 rows of lead atoms separate each zinc plate, assuming the lead grain is normal to the polished plane of the photomicrograph. This characteristic structure is not as evident, of course, in the very low zinc hypo-eutectic alloys.

Fig. 18 is the first photomicrograph in which the typical hyper-eutectic structure is to be found. In these alloys the zinc is in more massive plates and often passes through and along the grain boundaries of several of the lead grains. The lead grains are much smaller and are much freer from the hypo-eutectic zinc. An abnormal amount of zinc evidently freezes as primary zinc in these hyper-eutectic alloys. There is a tendency for the primary zinc plates to form in a fan shape as shown in Figs. 19 and 20.

Figs. 21 and 22 show zinc in the extremely massive form observed in the photomacrograph, Fig. 23. The segregation of primary zinc shown in the photomacrograph is rather peculiar. The ingot was very slowly cooled in an upright position, the primary zinc freezing out first and floating upward by reason of its low specific gravity compared to the liquid lead. However, the smaller zinc plates had collected very near to the top of the ingot while the general size of the plates increases toward the bottom. This is contrary to the usual behavior of particles in suspension, large particles always traveling faster than similar small ones. Perhaps the top of the ingot froze after considerable segregation had occurred but somewhat sooner than the lower part of the ingot. This would give the remaining zinc plates in the lower part more time to grow before freezing of the lead.

The temperature range involved in these tests is so narrow, 327° to 318° C., that no special device was needed to keep the rate of cooling or heating constant. The differential method used made the slight slowing up on cooling unimportant. The furnace required an input of 1.57 amps. at 110 volts to effect a drop in temperature of about 14° C. in one hour in the working range. This was the average speed of the cooling curves. Heating curves were run at about the same speed by increasing the input to 1.65 amps.

Figs. 24 and 25 indicate that the method is very satisfactory for indicating the beginnings of the liquidus and eutectic reactions. The experimental data in Table 2 are presented to show the character of the data from which the curves were plotted.

The break at 13.36 mv. indicates the beginning of freezing of lead solution crystals. A total deflection of 4.6 cm. was reached by the reflecting galvanometer in the differential circuit. Theoretically, the heat of crystallization continues to be absorbed by the melt rather uniformly until the eutectic break at 13.00 mv. is reached. This should cause a small continued deflection of the galvanometer until the eutectic temperature is reached. In this apparatus, however, heat is transmitted down the differential thermocouple wires to the region of the neutral body from the upper junctions, a distance of only one inch, when a difference of temperature occurs between these 2 regions. This effect counteracts continued movement of the galvanometer whenever the

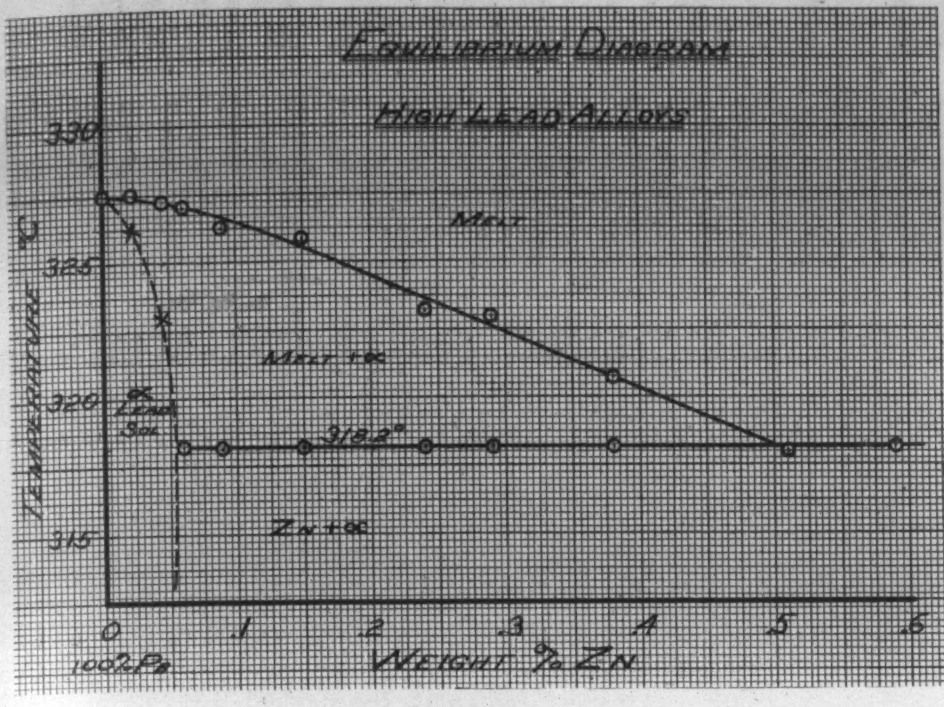


Fig. 27.

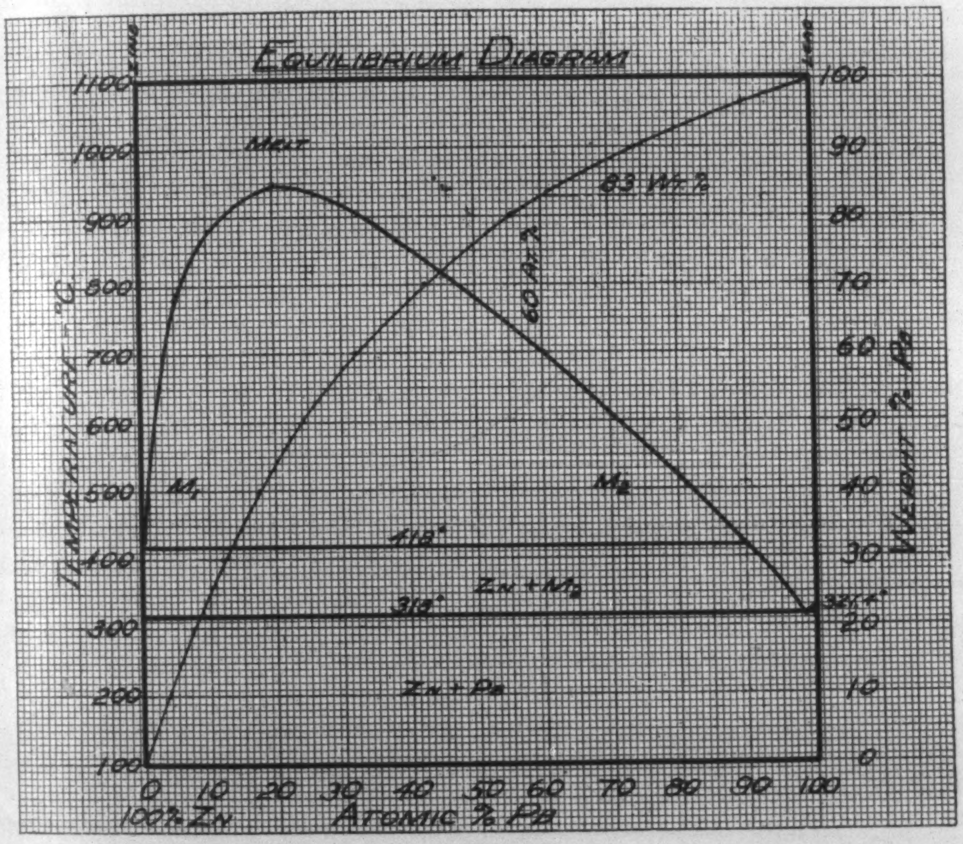


Fig. 28.

reaction occurs over a long enough period of time for the heat conduction to take place. This effect explains, for instance, the fact that the 0.06% Zn alloy had a shorter liquidus break than the 0.09 and 0.15% Zn alloys which freeze out less lead above the eutectic temperature. The 0.06% Zn alloy was cooled slower than the 2 of higher zinc content.

The 0.02% Zn cooling curve indicates the effect of unnatural conditions of cooling. The crucible was not held at its highest temperature long enough to insure equilibrium conditions. Although the rate of cooling was average, a cooling curve resulted which might be taken to indicate supercooling. No genuine case of supercooling was found in these tests. It may also be noted that the potentiometer indicator was not sensitive enough to detect any lowering of the liquidus due to the 0.02% zinc present in this alloy.

The general decrease in the length of the liquidus break and increase in the length of the eutectic break with increasing zinc content is evident from Fig. 24. The 0.51% Zn curve was run very slowly to detect any possible liquidus break and therefore the length of the eutectic break is not as great as it might otherwise be.

That no liquidus break on hypereutectic alloys could be detected is shown by the 0.59% Zn cooling curve. Inspection of the constitution diagram in Fig. 28 shows that a very slight amount of zinc should crystallize between the liquidus and the eutectic temperature, nearly all the alloy freezing as eutectic.

The heating curves in Fig. 25 are given as partial proof of the solubility of zinc in lead. The curve for pure lead shows the melting point to be slightly higher than indicated by its cooling curve. This slight lag in the apparatus was also found in several heating curves on eutectic alloys. These alloys showed a eutectic break on heating at about $^1/_{100}$ millivolt ($^1/_4$° C.) higher than for cooling. The 0.02% Zn and the 0.05% Zn curves show a change of slope at the points marked "X." These points have been used to determine the tentative solubility curve in Fig. 27. The limit of solubility at 318.2° C. was determined by the absence of a eutectic break in the 0.05% Zn alloy and the presence of a very small break in the 0.06% Zn alloy. It appears that the steep slope of the solid solution solidus line and the resulting low percentage of melting taking place per degree temperature rise is responsible for the lack of a more definite solidus break in these heating curves.

The equilibrium diagram, Fig. 27, has been constructed using the results of these curves.

Attempts at studying the effect of zinc on the hardness of lead were made early in the work. The effect of flow of metal under pressure made the ordinary hardness measurements unsatisfactory for these alloys. It was found that using a Rockwell machine with a diamond cone penetrator and using only the 10 kg. initial load, a rather wide range of readable, comparable hardness values was obtainable. The specimen was given a rather shiny polish that would reflect light, placed in the Rockwell machine, and the minor load applied for a period of 5 minutes. The movement of the penetration gage was indiscernible after this time. The penetrator made an impression about the size required for an ordinary Rockwell "0" to "20C" hardness; therefore a slightly larger than standard cone would be better suited to this test, since the Brale penetrator is ground accurately to an "R20C" hardness impression. The diameters of the impressions were measured at 100 × magnification and are given here in inches as measured.

Annealing had considerable effect on the hardness. The following data were taken from a set of uniformly chill cast ingots about one inch in diameter. On annealing, the alloys softened uniformly so that the shape of the hardness curve remained the same. It should be remembered that the "Diameter of Impression" recorded is a measure of the softness of the alloy. A calculated Brinell hardness of about "3" is obtained from this data.

% Zn	Diameter of Impression in Inches and at 100×
0.15	2.78
0.17	2.70
0.25	2.53
0.31	2.53
0.45	2.44
0.48	2.32*
0.89	2.31
2.01	2.32

*** It is significant that the hardness remained constant after the 0.48% Zn alloy. It is evident that zinc imparts much greater hardness in the form of eutectic than as the large zinc plates of the hyper-eutectic alloys. Alloys of much higher zinc content should, of course, again show an increase in hardness.**

Continued on page 313

PREFERRED ORIENTATION PRODUCED BY COLD ROLLING

in the Surface of Sheets of

Aluminum, Nickel, Copper and Silver

BY CLEVELAND B. HOLLABAUGH AND WHEELER P. DAVEY

(Concluded)

IV. INTERPRETATION OF THE DIFFRACTION PATTERNS

a. The General Method.

THE ranges of preferred orientation of the crystal fragments in the surfaces of the rolled samples of metal were determined by the method of Davey, Nitchie and Fuller.[6] This method depends upon the fact that a diffraction pattern, taken with a pencil of X-rays from a pin-hole slit, will show continuous diffraction rings if the crystal fragments have random orientations about the incident X-ray beam, but will show only detached arcs of these rings if the crystal fragments have preferred orientations about the incident beam. The length of these arcs is a measure of the degree of deviation from the mean preferred orientation.

The method may be considered to be made up of five steps as follows—

(1) Diffraction patterns of the rolled metal are made (a) with the X-ray beam in a plane which is perpendicular both to the surface of the metal and to the rolling direction, and (b) with the X-ray beam in a plane which is perpendicular to the surface of the metal and which includes the rolling direction. For our present purposes there is no advantage in still other patterns taken in other directions. Complete representation of orientations by means of "pole figures" requires still other diffraction patterns in order to avoid possible ambiguities which are unimportant here.

(2) A silver print is made of each of the negatives which show arcs, care being taken that the print is a true "positive" without reversal of the right and left hand sides. All determinations of preferred orientations by this method are best made with the aid of positive prints, no work being done on the original negative. From a knowledge of the wave-length of the X-rays used, the specimen-film distance, the diameter of the diffraction rings and the crystal structure of the specimen, the Miller indices are calculated for the atomic planes in the specimen corresponding to each diffraction ring. These indices are marked on the positive print, or on the card on which it is mounted, in order to properly identify each arc of each ring. The necessary calculations for the identification of crystal planes are discussed in a series of X-ray articles by Prof. G. L. Clark in the initial issue of METALS & ALLOYS. The angle which the specimen made with the horizontal at the time the diffraction pattern was made can always be calculated with sufficient accuracy from the specimen-film distance and from the position of the shadow of the specimen as recorded on the film.

(3) A large model of the crystal lattice of the metal undergoing examination is mounted on gimbals so that it may be given any desired orientation. This model must be made accurately to scale. The balls are preferably spaced three or four inches apart so that it may be possible to look *through* the model. The positive prints mentioned above are mounted one at a time in a vertical position at a convenient height and the model is set up in front between the print and the observer. A string is stretched from a vertical support to the model so that its direction is perpendicular to the plane of the positive print. This string represents the incident X-ray beam. It is often convenient to use an elastic tape instead of the string so that there may be no slack caused by adjusting the position of the model.

(4) Some diffraction ring is chosen in pattern (a) of step 1 which experience shows is convenient to use as a starting point in the interpretation, and the corresponding plane is identified on the model. The model is now turned so that this atomic plane is in the correct orientation to diffract to the center of one of the arcs on the diffraction ring. The degree of deviation in the actual specimen from this mean position may be found by simple calculation from the length and radius of the arc on the diffraction pattern. We have now fixed the mean location of this atomic plane but we have not found how it is oriented about an axis perpendicular to itself. The model is therefore rotated about a normal to this plane until some other plane is in a position to diffract to some spot in its ring. In general, this second plane will require that the model be rotated about an axis perpendicular to the string in order to place the second plane at its proper diffracting angle to the X-ray beam. Obviously this rotation must not be in excess of the amount permitted by pattern (b) of step 1 taken in a direction at right angles to the first.

(5) Starting with the mean orientation found in step 4 it is necessary to show first, that, within the limits of deviation from the mean orientation as shown by the arcs on the positive print, the assumed orientation of the model is able to account for the position, length, and relative intensity of every arc of every ring on the positive print, and second, that the assumed orientation does not predict still other arcs or rings which are absent from the positive print. This necessitates a systematic study of each of the simple atomic planes in the model. It often happens, as in some of the cases described in this paper, that more than one orientation must be assumed in order to account quantitatively for the experimental data.

b. The Determination of Preferred Ranges of Orientation from Changes Produced in Diffraction Arcs on Cold Rolling of Aluminum, Nickel, Copper and Silver.

Each of these four metals showed different types of orientation patterns except nickel and copper which were identical throughout their series. The interpretations of the patterns of aluminum and silver will be given separate discussions, while those of nickel and copper will be discussed together.

The diffraction patterns obtained from the cold rolled samples of aluminum, copper and nickel showed differences from those obtained from annealed samples, both when taken across the direction of rolling and when taken along the direction of rolling. This made it necessary to consider two patterns simultaneously to obtain a complete picture of the limitations of orientation existing in each sample. To do this it was necessary to modify the procedure originally outlined by Davey, Nitchie and Fuller. This modified procedure will be described at this point.

A face-centered cubic model, mounted on gimbals, was pictured as being the unit cell of a crystal fragment in the surface of the sheet of metal, which was in turn pictured as being in a horizontal plane. The positive print of the diffraction pattern taken with the X-rays impinging along the direction of rolling, mounted on cardboard and labeled as already described, was set up opposite the model so that it tilted away from the normal to the plane of the sample by an angle of 20°, and in such a position that its center spot was opposite the center of the model. The positive print of the diffraction pattern made with the X-rays impinging across the direction of rolling, was mounted in the same way in a position such that its lower edge was at right angles to the lower edge of the other one. The X-ray beam for each of these two patterns was visualized as coming in toward the model in a direction normal to the center spot of the pattern. The end of the sample entering the rolls first was visualized as being parallel to and next to the lower edge of the pattern taken along the direction of rolling. The lower edge of the pattern taken across the direction of rolling was parallel to the side of the metal sample, thus placing the end of the sample through the rolls first on the right hand side when looking across the sample toward this pattern. This setup placed the two diffraction patterns in the positions in which they were taken relative to a sample pictured as being in the horizontal plane in which the model is located. This arrangement made it convenient, when interpreting the diffraction patterns to refer the various positions of the model back to positions of the crystal fragments in the surface of the metal sheet.

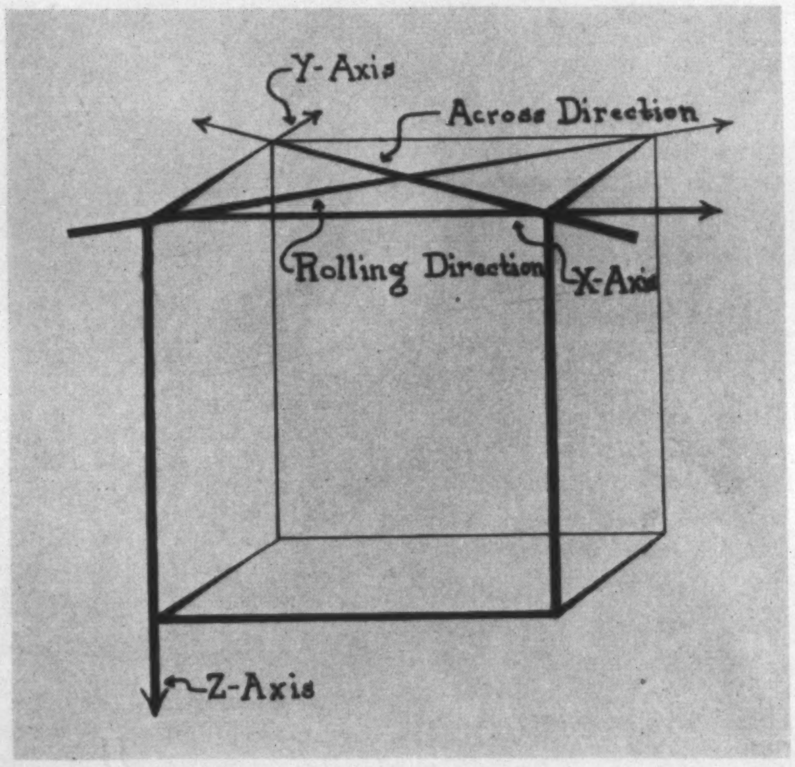


Fig. 3.—Convention of coördinates adopted for naming planes in crystal model

The next step was to select a convention of coördinates for identifying the individual planes of the various families with reference to the model. Picturing the model with its cube face in the horizontal plane and one of the face diagonals in the direction of rolling of the sample, the origin of coördinates has been selected as the corner of the cube toward the end of the sample which went through the rolls last. The X-axis is the edge of the cube to the right when looking along the direction of rolling, from the origin toward the end of the sample which entered the rolls first. The Y-axis is the corresponding cube edge to the left. The Z-axis is taken normal to the plane of the sample, with its positive direction downward. This convention is illustrated in Fig. 3.

In accounting for the relative intensities of the spots on the orientation patterns, the plausible assumption was made that the probability of a crystal fragment occupying a given position varies enormously as the location of this position is changed with respect to the limits of the preferred range. The probability of a crystal fragment finding itself in a given orientation was assumed to be almost negligibly small for orientations outside the preferred range, very small at the edge of the preferred range both around the direction of rolling and around the axis which lies across the direction of rolling, small for an orientation which lies at the end of one range and at the center of the other, and rapidly increasing to a high degree of probability as the center of both preferred ranges is approached. In the discussion of the diffraction of the individual planes, it will be shown that this assumption accounts for the intensities of the spots on the pattern.

To shorten the description to follow, a convention of terms has been selected for describing the various positions of the model in terms of the sample. The gimbals on which the model was mounted permitted the model to be rocked about a horizontal line which was perpendicular to the rolling direction. This axis of rotation was therefore parallel to the surface of the specimen. This was called for purposes of brevity, the *across* axis. Rotation was considered to be positive when it was clockwise looking along the *across* axis toward the diffraction pattern. The gimbals also permitted the model to be rocked about an axis perpendicular to the *across* axis, which was in the horizontal plane when there was no rotation about the *across* axis. This axis will be termed the *along* axis. Rotation was considered to be positive, when it was clock-wise looking along the *along* axis toward the diffraction pattern. The zero position with respect to each axis is the position in which the cube face of the model is in the horizontal plane. It is important to note that the *along* axis will only lie in this direction when the cube is in its zero position about the *across* axis. The *across* axis will always lie in the horizontal plane in a direction at right angles to the direction of rolling. In referring to the diffraction patterns taken in the two directions, the diffraction pattern taken with the X-rays impinging on the sample across the rolling direction will be termed the *across* film. The one taken with the X-rays impinging in the direction of rolling will be termed the *along* film.

1. **Aluminum.** The diffraction patterns of the series of rolled samples of aluminum listed in Table 2 show differences from one sample to the next as the number of passes through the rolls is increased, which do not appear to be progressive changes. The general appearance of the patterns showed however that the structures are closely related. These differences made it necessary to make an independent interpretation of each set of patterns. To show how this was done the results of the interpretation of the two patterns from one sample will be given in detail. As the patterns of the last sample of the series, No. 11, which had been given 10 passes through the rolls, represented the most complex structure shown they have been chosen for discussion.

Fig. 4 is a positive print of the diffraction pattern obtained across the direction of rolling on Sample 11 with filtered radiation. The rings on this pattern are no longer continuous as they are on the pattern of Fig. 1. This indicates the presence of a preferred orientation around this direction. Fig. 5 is a positive print of the diffraction pattern obtained along the direction of rolling on this sample. This pattern likewise shows the presence of a preferred orientation around the direction in which it was taken, i. e., around the direction of rolling.

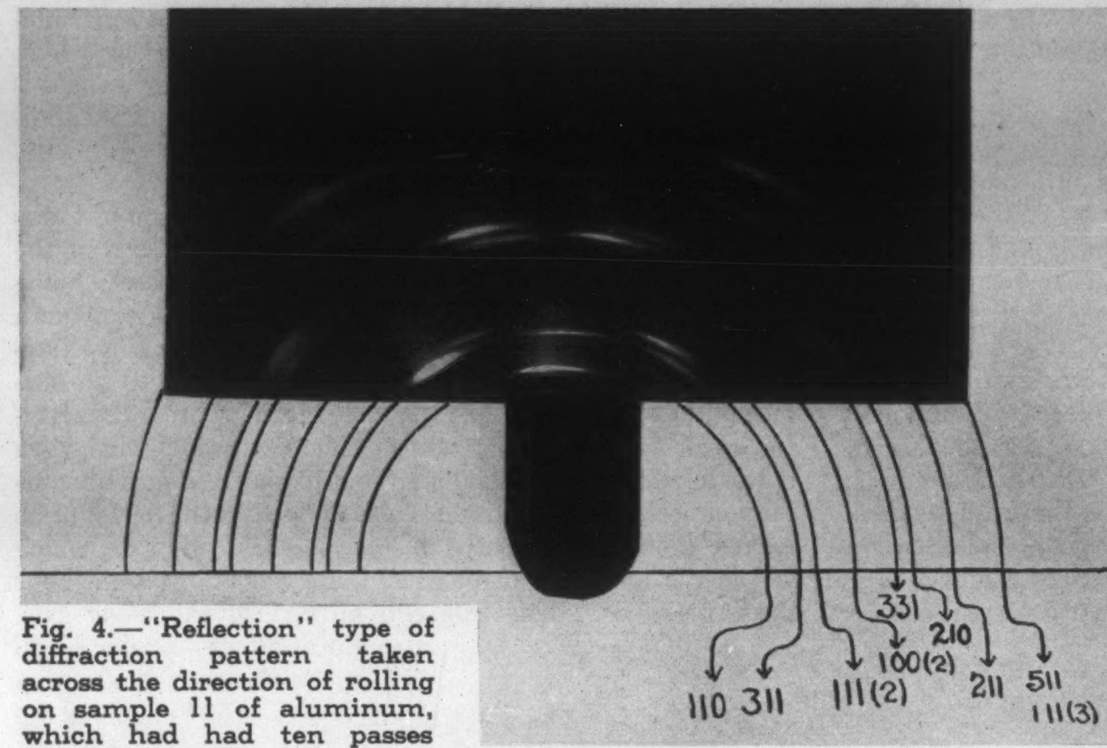


Fig. 4.—"Reflection" type of diffraction pattern taken across the direction of rolling on sample 11 of aluminum, which had had ten passes through the rolls

These two diffraction patterns, labeled and mounted as shown in Figs. 4 and 5, were placed in positions relative to the face centered cubic model as shown above. The first step in the interpretation was to make an examination of the diffracting possibilities of various planes through the model in both the *along* and the *across* direction according to the method of Davey, Nitchie and Fuller, with the slight modifications in set-up already described. This examination gave a tentative range of orientation positions. The diffracting possibilities of each plane in every possible position in this range were then examined both the *across* and *along* directions to prove that this range of positions accounted for both diffraction patterns and could give no others. For purposes of record, the results of this examination will be given in detail for each set of planes. These results prove that the tentative orientation range selected accounts for the diffraction patterns obtained and no others.

The orientation ranges which were tentatively selected and which were proved to account for the patterns obtained can be visualized in terms of the sheet foil as follows: Consider for purposes of reference the unit face centered cube of a crystal fragment with its cube face parallel to the sheet surface and with one of its face diagonals parallel to the direction of rolling. Using the other face diagonal as an axis, i. e., as the *across* axis, allow the cube to rotate between the limits of +29° and +45° and between the limits of −20° and −42°. Now using the first diagonal as an axis, i. e., as the *along* axis, with the cube being in each of the above limits in turn, allow a rotation between the limits of +2° and +35° and between the limits of −2° and −25°. Anywhere within these limits the unit cell of the crystal fragment will be within the preferred range of orientation.

Proof is given below that this range of preferred positions accounts for the diffraction pattern shown in Fig. 4, which was taken with X-rays impinging across the direction of rolling. Each family of planes which can diffract in the range of angles recorded on the plane will be taken in turn in the order which was found advantageous in the original work, and the diffraction of each plane in the family will be accounted for.

{111}. This family is made up of 4 sets of planes, only 2 of which can diffract in the preferred range in the *across* direction.

(111). This plane can only diffract to the film in the range between the angles of +29° and +45° about the *across* axis and in so doing accounts for the entire range of spot 1. This diffraction requires an angle of +3° about the *along* axis.

$(11\bar{1})$. This plane can only diffract to the film between the angles of −20° and −42° *across* at an angle of +3° about the *along* axis and in so doing accounts for the entire range of spot 2.

{110}. This family is composed of 6 sets of planes, only 2 of which can diffract in the limitation set by the {111} and {311} planes.

(101). This plane can diffract only in the range between +29° and +45° *across*. At a position of +29° *across* and +18° *along* this plane diffracts to the center of the single {110} spot. On going to +45° of the *across* range, the *along* angle remains the same and the plane now diffracts to the right hand edge of its spot.

$(01\bar{1})$. This plane can diffract only in the range between −20° and −42° *across*. Between these 2 limits the diffraction can sweep the entire extent of the spot. To diffract from this plane the unit cell of the crystal fragment must make an angle of +35° *along* when at −42° *across* and +25° *along* when at −20° *across*.

{100}. This family has 3 sets of planes.

(001). This is the only plane of this family which can reach a diffracting angle within the limits of the preferred range. At −42° *across* and +5° *along* it diffracts to the left hand edge of spot 1. This position is at the extreme edge of the *across* range and is near the edge of the *along* range. The probability of any given crystal fragment occupying such a position is low, so that (001) contributes very little energy to the left hand edge of spot 1. At −20° *across* the model would have to be set at 0° *along* in order to be able to diffract to the right hand edge of spot 1. The probability of a given crystal fragment occupying such a position outside the preferred range is extremely low, so that (001) contributes almost nothing to the right hand edge of spot 1. This then explains the low intensity of spot 1. Between +29° and +45° *across* the (001) plane can diffract to the entire range of spot 2, but again requires an angle of 0° *along*. In this case as before the probability of a crystal fragment occupying such a position outside the preferred range is extremely low so that the (001) plane contributes very little to spot 2. This explains the very low intensity of this spot.

{311}. This family has 12 sets of planes, only 3 of which can diffract in the preferred ranges.

$(\bar{1}13)$. This plane can diffract to the pattern in both preferred ranges. When at −42° *across* and at +30° *along* the beam will be diffracted to the left hand edge of spot 1, while at −20° *across* and +25° *along* the beam will go to the right hand edge of this spot, thus accounting for the entire spot. At +29° *across* and +25° *along* the beam will strike the pattern at the left hand edge of spot 3 and at +45° *across* and +25° *along* it goes to the right hand edge of spot 3. This range then accounts for all of spot 3.

$(1\bar{1}3)$. This plane can diffract only in the positive *across* range. At +29° *across* and −20° *along* this plane will diffract the beam to the left of the center of spot 2. The intensity will be low because the diffracting angle is at the edge of the *along* range. At +45° *across* and at −2° *along*, the beam strikes the right hand end of spot 2, with the intensity still very low.

$(11\bar{3})$. This plane can diffract only in the negative *across* range. At −42° *across* and +2° *along*, the beam will be diffracted to the left hand edge of spot 2. At −20° *across* and +2° *along* the beam diffracts to the right hand edge of the center spot. The intensity will be low all the way across the spot.

{331}. There are 12 of these planes, only 6 of which can show any diffraction whatever within the preferred ranges.

(331). This plane can only diffract in the positive *across* range. At +45° *across* and +15° *along* this plane will diffract the beam to the right hand edge of spot 1. On approaching the other end of this range the plane ceases to diffract at +32° *across* because at smaller angles than this the diffracting angle would require us to exceed the limiting angle of +35° *along*.

$(33\bar{1})$ can diffract to the film in the negative *across* range. At an angle of −42° *across* and 0° *along* this plane would diffract to the left hand edge of spot 4, but the intensity would be extremely low because the crystal fragments would have to lie outside the *along* range. At −20° *across* and +18° *along* this plane diffracts to the extreme right hand edge of spot 4. The *along* angle now insures good intensity.

(313) can diffract to the film only in the positive range. At +29° *across* and +25° *along* it diffracts to the left hand edge of spot 2. At +45° *across* and +25° *along* the beam will be diffracted to the right hand end of spot 2.

$(31\bar{3})$ can diffract to the film only in the negative range. At −42° *across* and −20° *along* the beam diffracts to the left hand edge of spot 3 with good intensity. At the other end of the range, −20° *across* and −18° *along*, the beam goes to the right hand edge of spot 3, thus accounting for the entire spot.

(133) can diffract to the film only in the positive range. At +29° *across* and −19° *along* the beam is diffracted to the left hand edge of spot 2, with good intensity. At +45° *across* and −20° *along* the beam goes to the right hand edge of spot 2.

$(13\bar{3})$ can diffract only in the negative range. At −42° *across* and +25° *along* the beam is diffracted to the left hand edge of spot 3, with good intensity. At the other end of the range, −20° *across* and +28° *along*, the beam goes to the right hand edge of spot 3.

{210}. This family has 12 sets of planes, only 4 of which can diffract in the ranges of orientation given above.

(102) can diffract in both the negative and positive ranges. At −42° *across*, an angle exceeding the limit of +35° *along* would be necessary for diffraction, but at −40° *across* and +35° *along* it starts diffracting and the beam goes to the left hand end of spot 1. At −20° *across* and +30° *along* the beam goes to the right hand end of spot 1. At +29° *across* and +26° *along* the plane diffracts to the left hand edge of spot 3 with good intensity, while at the other end of the range, +45° *across* and +26° *along* the beam goes to the right hand edge of spot 3, still with good intensity.

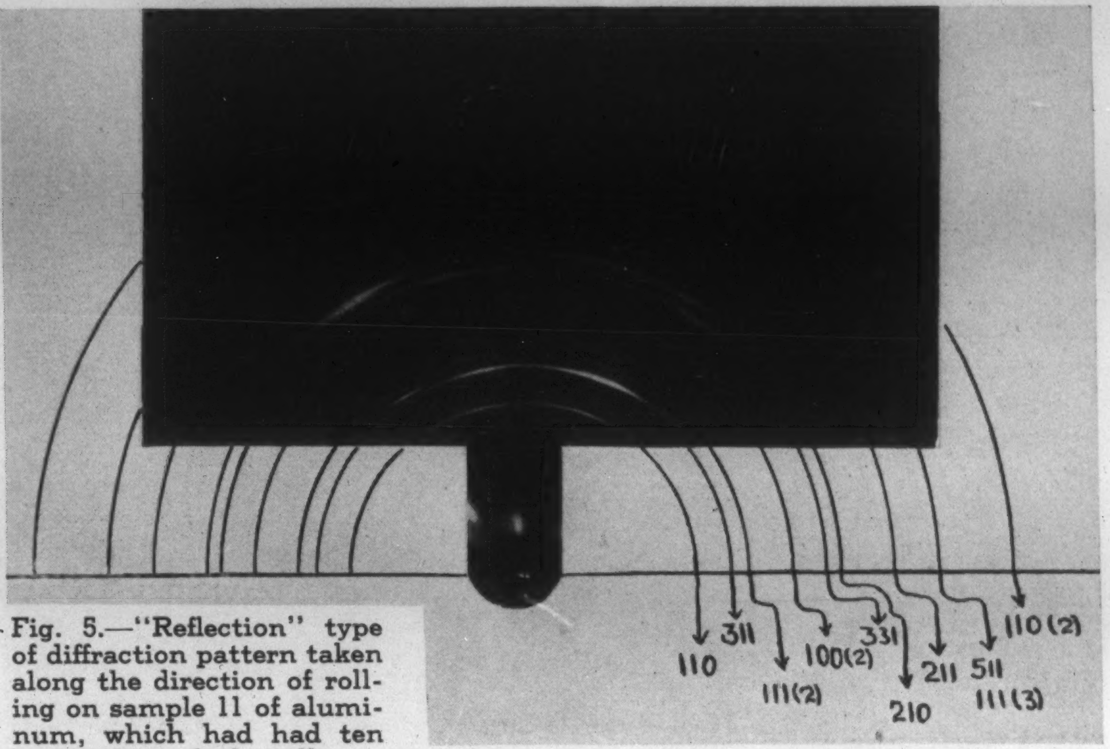


Fig. 5.—"Reflection" type of diffraction pattern taken along the direction of rolling on sample 11 of aluminum, which had had ten passes through the rolls

$(\bar{1}02)$ can diffract in both negative and positive ranges. At −42° *across* and −20° *along* the beam will be diffracted to the left hand edge of spot 2 with good intensity, while at −20° *across* and −15° *along* it goes to the right hand edge of spot 2. At +29° *across* and −10° *along* the beam will be diffracted to the left hand edge of spot 4 with good intensity. At +45° *across* and −8° *along* the diffracted beam will go to the right hand edge of the spot with good intensity.

(012). This plane can diffract in both positive and negative ranges. At −42° *across* and −10° *along* the beam diffracts to the left hand edge of spot 1 with good intensity. At −20° *across* and −18° *along* the beam goes to the right hand edge of spot 1. At +29° *across* and +15° *along* the beam will be diffracted to the left hand edge of spot 3 with good intensity. At +45° *across* and +15° *along* the beam goes to the right hand edge of this spot.

$(0\bar{1}2)$. This plane diffracts in both the positive and negative ranges. At −42° *across* and +28° *along*, the beam is diffracted to the left hand edge of spot 2 with good intensity. At −20° *across* and +28° *along*, the beam goes to the right hand edge of spot 2 with good intensity. At +29° *across* and +30° *along* the beam diffracts to the left hand edge of spot 4 with good intensity. On rotating toward the other end of the range diffraction stops at +42° *across*, because beyond this point the diffracting angle requires an *along* angle beyond the limit of preferred orientation. At this setting the beam strikes the right hand edge of spot 4 with good intensity.

{211}. There are 12 sets of planes in this family, only 4 of which can diffract in the preferred ranges.

$(11\bar{2})$ can diffract to film only in the negative *across* range. At −42° *across* and +12° *along*, this plane diffracts to the center of spot 2 with good intensity, while at −20° *across* and +2° *along*, the beam is diffracted to the end of spot 3. The unit cell is here at the end of both its *along* and *across* ranges, so the number of crystal fragments will be low. Therefore, the line will dwindle to a low intensity at this end.

(112) can diffract only in the positive range. At +29° *across* and +10° *along* the beam is diffracted to the left end of spot 2, with good intensity, while at +45° *across* and +7° *along*, the beam goes to the right hand edge of spot 2 with good intensity.

$(21\bar{1})$ can diffract only in the negative range. At −42° *across* and −20° *along*, the beam diffracts to the left edge of spot 3 with good intensity. At −20° *across* and −14° *along*, the beam diffracts to the right hand edge of spot 3 with good intensity.

(121) can diffract only in the positive range. At +29° *across* and −5° *along*, this plane diffracts to the left hand edge of spot 1 with good intensity. At +45° *across* and −18° *along*, the beam is diffracted to the right hand edge of spot 1 with good intensity.

{511}. This family will not be considered because its diffraction is superimposed on that from the {111} in its third order. It is probably very faint as the ring has exactly the same appearance as that due to the second order from {111}.

Proof will now be given that the range of preferred positions given above which were used to account for the pattern taken across the direction of rolling on Sample 11, will also account for the patterns taken along the direction of rolling on this sample.

{311}. Of the 12 planes in this family there are 2 which can diffract in the preferred range of orientation positions. The diffraction of these two planes will be discussed in turn.

$(1\bar{3}1)$. This plane can diffract between +22° *along* and +35° *along* when set at the −42° limit of the *across* range, and can diffract to spot 1 between these limits. The intensity of diffraction will be low because it requires the crystal fragment to be located at the end of its *across* range.

$(11\bar{3})$. This is the plane which established the limits of the range around the *along* axis because, if it had been allowed an unlimited rotation about the *along* axis, it could have been diffracted to the portions of the film where no diffraction was recorded. At −25° *along* and −38° *across*, this plane diffracts to the left hand side of spot 1. At −2° *along* and −30° *across* its diffracted beam goes to the right hand side of spot 1. At +2° *along* and −30° *across* it diffracts to the left hand side of spot 2 and at +35° *along* and −38° *across*, it strikes the right hand side of spot 2.

{111}. There is only one plane of this family that approaches a diffraction angle. The (111) plane can diffract at a point 5° in excess of the +45° *across* limit, over the entire range in the *along* direction covering a complete arc on the pattern. A few stray (111) planes are probably responsible for the very faint continuous {111} (2) ring.

{100}. There is no plane of this family which can diffract in the orientation range specified. If the (010) plane is set at +46° *across*, (a point 3° beyond the limit in this direction), and at +24° *along* it can diffract to the very faint right hand end of the {100} (2) spot. The fact that this plane can only diffract when placed outside the preferred range explains the faintness of this spot as compared with the remainder of the pattern. The (100) plane can also diffract at +48° *across* at angles between 0° and +24° *along* and accounts for both the position and the low intensity of the very faint left hand spot on this ring.

{331}. There are 12 planes in this family, only 4 of which can possibly diffract an X-ray beam impinging in the *along* direction.

(313). At +35° *along* and +29° *across* this plane diffracts the X-ray beam to the right hand end of spot 1, but the beam will be of low intensity, because the crystal fragment is at the edge of its range in both directions. On going to the other limit of −25° *along* and +32° *across*, this plane diffracts to the left hand edge of spot 1. The spot on the pattern shows no breaks corresponding to the +2° and −2° limits of the *along* range, because another plane (133) is also diffracting to this spot.

$(3\bar{3}1)$. At −25° *along* and −30° *across* this plane diffracts to the left hand edge of spot 2 and stops diffracting at −3° *along* and −42° *across*, at which point it is diffracting to the right hand edge of spot 2. It cannot diffract at all in the positive side of the *along* range.

(133). At −25° *along* and +24° *across* this plane diffracts to the right hand edge of spot 1 with poor intensity, while at −2° *along* and +29° *across* the beam goes just to the left hand edge of spot 2, still with poor intensity. At +2° *along* and +29° *across* the beam goes to the left hand edge of

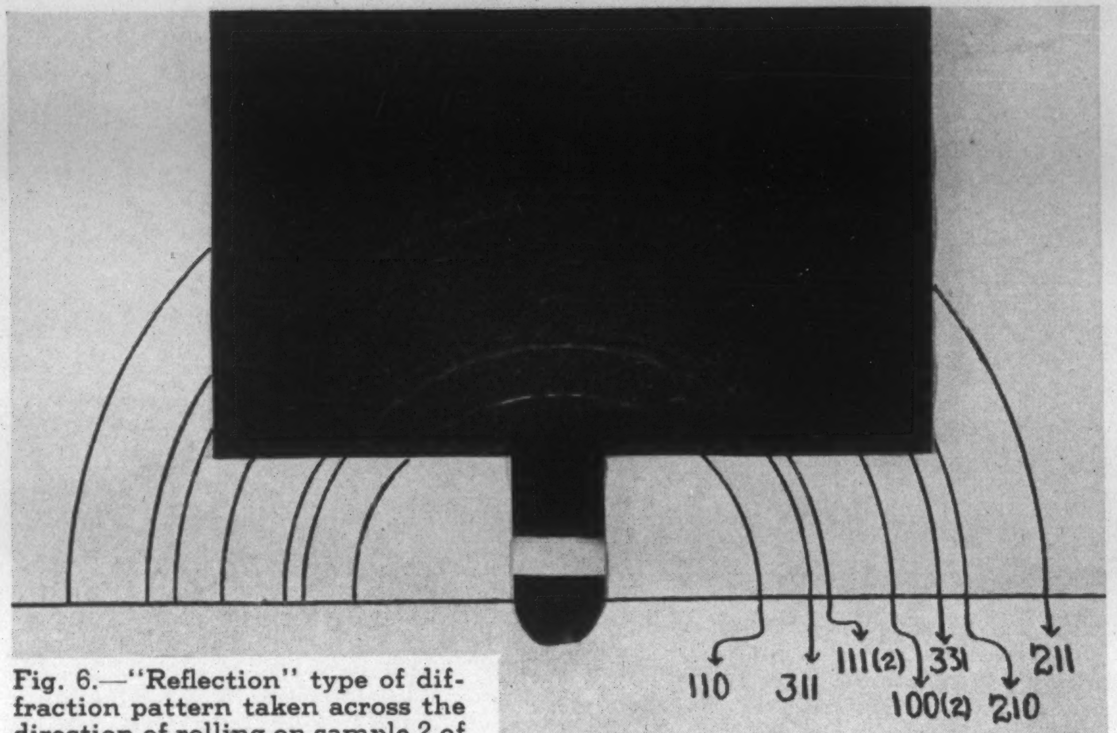


Fig. 6.—"Reflection" type of diffraction pattern taken across the direction of rolling on sample 2 of nickel, which had had one pass through the rolls

spot 2, while at +35° *along* and +45° *across* it goes to the right hand edge of spot 2. In this range, then, this plane diffracts to all of spot 2 with fair intensity.

$(1\bar{3}3)$. At +35° *along* and −30° *across* the beam is diffracted to the right hand edge of spot 1. The diffraction cannot occur at a smaller angle than +7° *along* and −42° *across*. At this point it goes to the left hand of the edge of the tail of spot 1. This plane explains the tailing off of this spot. On the right hand edge of the spot it can diffract with good intensity, because the crystallites in the center of the preferred range are diffracting from this plane; on the left hand edge of the spot it will be very low in intensity, because the crystal fragment must be right on the edge of the preferred range in both directions.

{210}. This family consists of 12 sets of planes, 5 of which can diffract in the *along* direction.

(012) At −25° *along* and −42° *across*, this plane will diffract to the left hand edge of spot 1. At −2° *along* and −38° *across*, the beam would go to the right end of spot 1. At the left end of spot 1, the intensity will be low, because the crystal fragments will have to be at the −42° limit, but the beam will get stronger toward the right end. At −2° *along* and −35° *across* the beam will diffract to the left hand end of the dim part of spot 2, while at −25° *along* and −35° *across*, the beam will be at the junction of spots 2 and 3.

$(0\bar{1}2)$. Diffraction will first occur on the negative end of the *along* range at −12° *along* and −42° *across*, and the beam will strike the left end of spot 1. At −3° *along* and −35° *across*, the beam goes to the right end of spot 1. At +2° *along* and −40° *across*, the beam goes to the left end of the weak part of spot 2. At +35° *along* and −32° *across* the beam goes to the right end of spot 2.

$(\bar{1}02)$. At −25° *along* and −35° *across*, the plane will diffract to the left end of spot 2, while at −2° *along* and −30° *across* it diffracts to the right end of spot 2. At +2° *along* and −30° *across*, the beam goes to the left end of spot 3, while at +25° *along* and −42° *across* the beam goes to the right end of spot 3.

(201). At −25° *along* and +45° *across* this plane will diffract to the left end of spot 1, while at +36° *along* and +30° *across*, the beam will be diffracted to the right hand edge of spot 1. The spot shows no break in intensity corresponding to the gap in the *along* range between −2° and +2°, because of the diffraction of another plane, (012), to this point.

(021). At −25° *along* and +29° *across*, the beam will diffract to the left end of spot 3. At −4° *along* and +35° *across*, the beam goes to the right hand end of spot 3. At +2° *along* and +35° *across* it goes to the right hand end of spot 3, while diffraction can occur only to +18° *along* and +45° *across* where it strikes the right end of spot 3.

We have, therefore, accounted for the positions and intensities of all the spots on the films taken in both the *along* and the *across* directions of Sample 11; we have accounted for the absence of absent arcs on both films; and we have shown that this orientation range will give no spots not recorded on the films. Further, we have conclusive evidence that the cube cannot be rotated about its Z-axis so that the *across* face diagonal is more than 4° from the *across* axis, since it was found by trial that a rotation of more than 4° made it impossible to fulfill the above conditions.

The interpretation of the patterns of the other samples of this rolling series (Table 2) of aluminum was carried out in exactly the same manner as that described above. Table 3 lists the angular limits of the orientation ranges shown by each sample of the series.*

2. Nickel and Copper. The diffraction patterns of the corresponding samples of nickel and copper are identical in every respect, except for the differences in the radii of the diffraction arcs, due to the different lattice parameters of the two metals. The diffraction patterns from the nickel and copper samples listed in Table 2 show a progressive change from one sample to the next as the number of passes through the rolls is increased. This change is indicated by a progressive decrease in the intensity of the {111} (2) diffraction ring on the patterns made with the X-rays impinging along the direction of rolling. A comparison of Fig. 6 with Fig. 8 illustrates this change. No other change can be detected in the patterns made with X-rays impinging along the direction of rolling. The patterns made with the X-rays impinging across the direction of rolling, show a progressive change in four diffraction arcs. The central section of the {111} (2) arc shows a progressive decrease in intensity with an increase in the number of passes through the rolls, while the two end sections show a corresponding increase in intensity. The ends of the {100} (2) arc fade out leaving this ring with definite ends which are not formed by the shadow of the specimen. The {211} arc and the {311} arc show the appearance of two regions of progressively increasing intensity on either side of the central section. These changes in the cases of both nickel and copper are progressive changes in the intensities of the regions and not in their limits. The limits of the altered portions of each arc are unchanged by the number of passes through the rolls. These changes can be seen by comparing Figs. 7 and 9.

Table 3.—Orientation Ranges Measured in Aluminum*
(Samples Listed in Table 2)

Sample No. See Table 2	Orientation Ranges Around the *Across* Axis (Angle between surface of sheet and line MN of Fig. 3)	Orientation Ranges Around the *Along* Axis (Angle between the original position of KL of Fig. 3 in the surface of the sheet and its limiting position when the crystal is rotated about MN as an axis)
2	From +22° to +38°	From −24° to −33°
3	From +22° to +38°	From +14° to −16°
4	From +20° to +38°	From −20° to −38°
5	From +12° to +38°	From −16° to −26°
6	From + 8° to +38°	From +10° to −26°
7	From + 8° to +30°	From −12° to −24°
8	From +24° to +44°	From 0° to −12°
9	From +12° to +34° From −14° to −38°	From +14° to −18°
10	From +22° to +38° From −18° to −28°	From + 4° to +18° From − 4° to −34°
11	From +29° to +45° From −20° to −42°	From + 4° to +35° From − 4° to −25°

* For explanation of nomenclature and signs, see text, Section IV, part b.

---

* Our results have not been expressed in terms of the pole figures since they have been derived for 2 directions only. In order to make any pole figure valid it would have been necessary to have taken and interpreted many more diffraction patterns with other orientations of our specimen-sheets. This would have increased the already great labor of interpretation of films without contributing very much toward our main objective, namely, a decision as to whether or not valence electrons affect orientation.

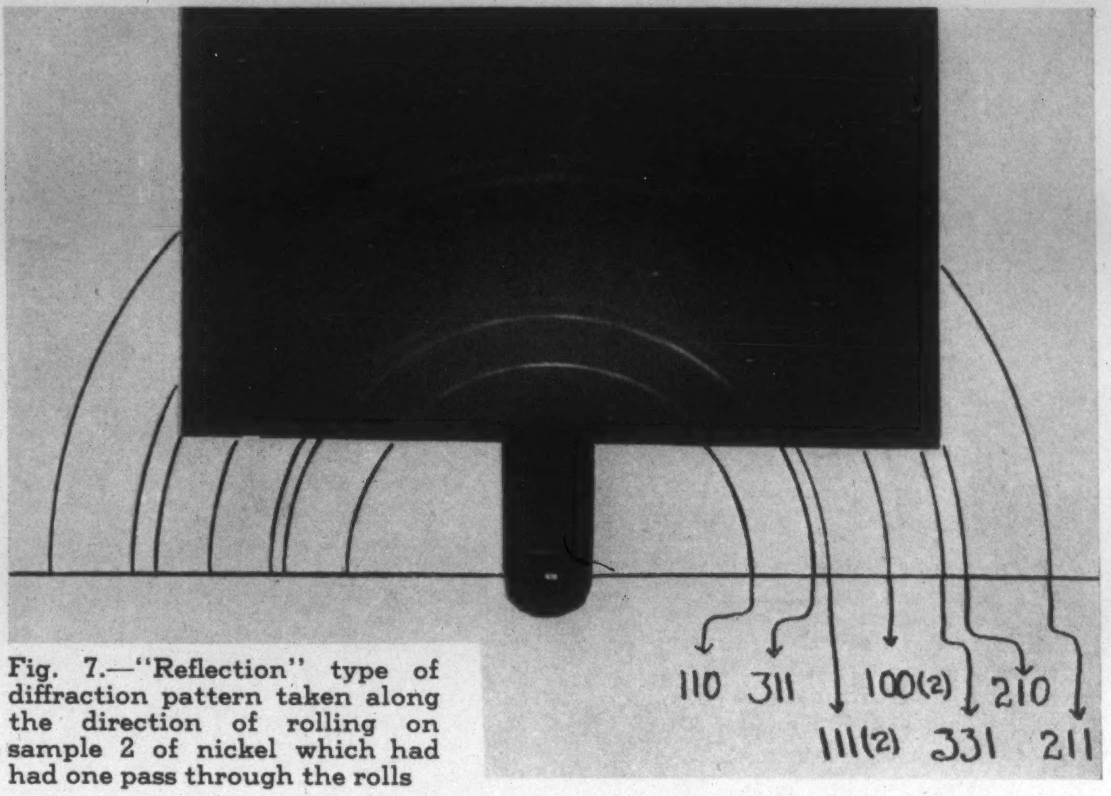


Fig. 7.—"Reflection" type of diffraction pattern taken along the direction of rolling on sample 2 of nickel which had had one pass through the rolls

These progressive changes indicate that in nickel and copper more and more of the crystal fragments are rolled into the preferred range as the number of passes through the rolls is increased. The first pass serves to crush the crystal grains, but produces little orientation, as is demonstrated by the continuous rings of Figs. 6 and 7. The preferred orientation begins to show only very gradually as the number of passes through the rolls is increased. From the pass after which the noticeable orientation first began to take place, to the last pass which the samples were given, no alteration occurred in the angular limits of the preferred range. Successive passes through the rolls did, however, increase the percentage of crystal fragments lying in the preferred range of orientation. Almost complete preferment of orientation was obtained after the last pass through the rolls. To determine what this preferred condition was and to measure its angular limits, it was only necessary to study the diffraction patterns which had had the greatest number of passes through the rolls, i. e., two similar to those shown in Figs. 8 and 9.

This was done, using exactly the same modification of the method of Davey, Nitchie and Fuller that has already been described above for the determination of orientation in aluminum. The interpretation of the diffraction patterns of the rolled samples of nickel and copper (Figs. 7 and 8) demonstrated the presence of a single range of preferred positions, which was symmetrical with respect to the surface of the foil. This symmetrical preferred range in nickel and copper can be visualized as follows: Consider for purposes of reference the unit face centered cubic cell in a crystal fragment in the surface of the rolled sheet of metal, with its cube face parallel to the surface of the sheet and with its face diagonal parallel to the direction of rolling. Using the *across* face diagonal as an axis, allow this unit cell to rotate until the *along* face diagonal makes an angle of not more than 38° above or below the direction of rolling. Now allow the unit cell to rotate about the *along* face diagonal, so that it makes an angle of not more than 45° above or below the *across* axis. Any position within this range of positions is within the limits of the preferred orientation found here.

To express this range of orientation in the convention of terms and signs used with aluminum, we can say that the unit cube may have a rotation of 38° about the *across* axis and a rotation of 45° about the *along* axis.

The families of planes which have the possibility of diffracting to the film will be considered in the order of increasing radius beginning with the diffraction ring of smallest radius recorded on the film. A glance at Figs. 7 and 8 shows this to be the {110} family.

{110}. There are 6 sets of planes in this family. Of these planes the $(10\bar{1})$, (101), (011) and $(0\bar{1}1)$ can diffract in both the *along* and the *across* directions and account for continuous arcs on both patterns.

{311}. There are 12 possible sets of planes in this family. Of these 12 sets, only the (113), $(\bar{1}13)$, $(1\bar{1}3)$ and the $(11\bar{3})$ can diffract in the preferred range of positions. A consideration of their diffraction shows them to account for continuous arcs on both the *across* and the *along* pattern.

{111}. There are 4 sets of planes in this family. The (111) plane accounts for the left hand spot on the {111} (2) arc of the *across* film. When the model is at the end of its positive *across* range, +38°, this plane diffracts to the right hand edge of this spot, provided the face diagonal of the (001) plane is within an angle of 4° of the rolling direction. When at the other end of its range, −38° *across*, this plane diffracts to a point below the shadow of the specimen off the left end of this spot. Nowhere within the preferred range of positions can this plane diffract in the *along* direction.

The $(11\bar{1})$ plane accounts for the right hand spot of the {111} (2) arc on the *across* film. When the cube is at the negative end of its range, −38° *across*, this plane diffracts to the left hand edge of this spot. When at the positive end of its preferred range, +38° *across*, this plane diffracts to a point below the shadow of the specimen on the right hand end of the arc. This plane cannot diffract to the *along* film anywhere within the preferred range.

The $(1\bar{1}1)$ plane can diffract both in the *across* and in the *along* direction when the cube is at the positive end of its along range, +45°. When in this position a rotation, through the preferred range, about the *across* axis, will allow the crystal to diffract to the {111} (2) arc on the *across* pattern, even in the center which fades out almost completely with continued rolling. The position necessary for this plane to diffract is one on the extreme edge of the preferred range around the *along* axis. Since continued rolling makes the central portion of the *across* ring increasingly fainter, it is evident that the rolling is decreasing the probability of a crystal fragment being in a position such that this plane can diffract. This is in agreement with the fact that in order that the $(1\bar{1}1)$ plane may diffract at all, the crystal fragment must occupy such a position that its unit cell is at a +45° *along* position, i. e., at the very edge of the preferred range. In this position this plane can also diffract to the *along* pattern, at the center of the {111} (2) arc. This arc becomes very faint with continued rolling. The same explanation of the decrease in intensity applies here that was given for the center of this arc on the *across* film. When the unit cube is moved to smaller positive *along* angles, the condition of diffraction for this plane in the *along* direction becomes increasingly harder to fulfill, until in the median position it can no longer diffract at all.

The $(\bar{1}11)$ behaves in exactly the same way as the $(1\bar{1}1)$ plane, except that its diffraction takes place at a −45° *along* position, instead of in a +45° *along* position.

{100}. There are 3 possible sets of (100) planes. Only one of these 3 sets, $(00\bar{1})$, can diffract in the preferred range. In the *across* direction in the range between +38° and −38° *across*, this plane sweeps the entire {100} (2) arc, with a setting at 0° *along*. At +38° *across*, it diffracts to the exact right hand limit of this arc and at −38° *across* diffracts to the exact left hand edge of the arc. In the *along* direction the $(00\bar{1})$ plane can diffract over the entire arc with an *across* angle of 0°. The extent of the 45° range *along* is necessary to account for the entire arc on the *along* pattern.

{331}. There are 12 sets of planes in this family, 10 of which can diffract in the *across* direction and 5 of which can diffract in the *along* direction. The {331} arc on the *across* pattern shows regions of increased intensity, superimposed on a continuous background. The diffraction of each of the 10 planes which can diffract in the *across* direction will be considered in detail, in order to explain the positions and intensities of these spots. The {331} arc on the *along* film is continuous and is uniform in intensity. The difference between these 2 arcs in the 2 directions is due to the greater range of positions about

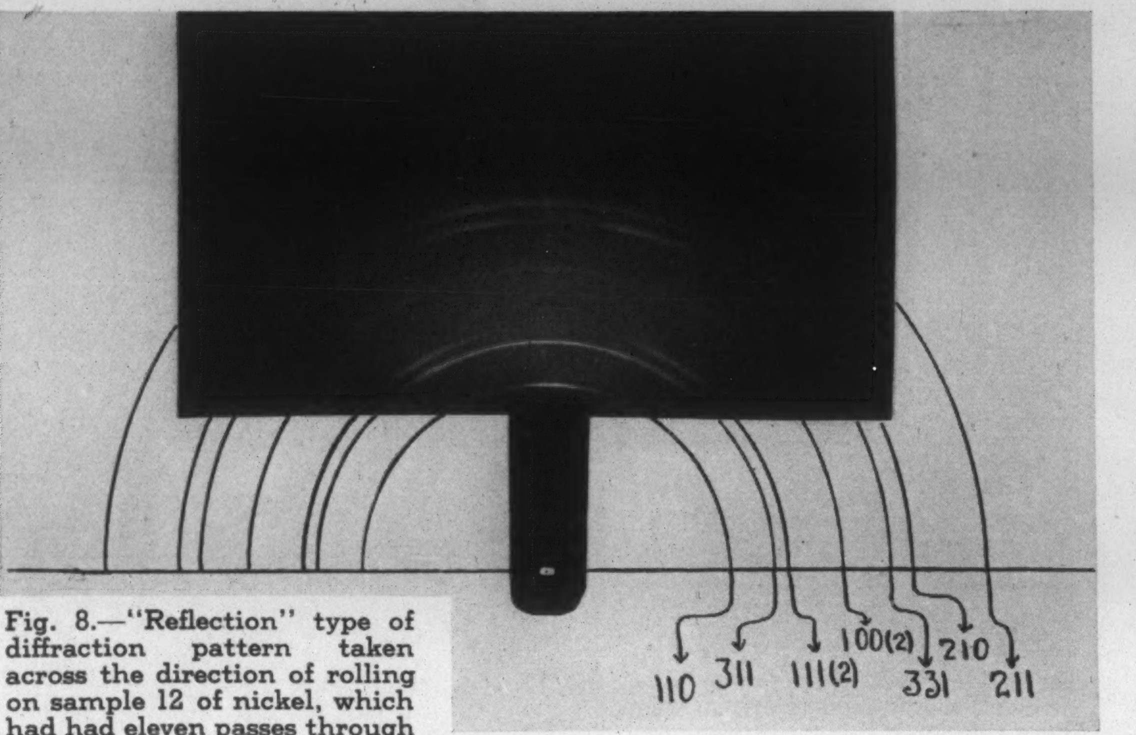


Fig. 8.—"Reflection" type of diffraction pattern taken across the direction of rolling on sample 12 of nickel, which had had eleven passes through the rolls

the *along* axis. This can be seen at once in the following treatment of the diffraction of these planes in the *across* direction, if limits of 45° are substituted for those of 38°.

The (331) plane accounts for a short sector on the left hand end of the $\{331\}$ arc, but will give very weak diffraction, since the cube must be near the end of its *along* range for it to diffract. The same is true of the $(33\bar{1})$ plane except that it accounts for a sector on the right hand end of the arc.

The (313) plane at +38° *across* diffracts to the right hand edge of the left hand spot, and on the other end of the *across* range it goes off the left hand end of the arc.

The $(\bar{3}13)$ plane at +38° *across* diffracts to the right hand edge of the arc. On the −38° end of the *across* range, it diffracts to the left hand edge of the left hand spot.

$(3\bar{1}3)$ will sweep the entire arc between the limits of ±38° *across*, but will diffract very weakly due to being near the edge of the range around the *along* axis.

The $(31\bar{3})$ plane diffracts to the center of the arc at −38° *across*, but the diffraction will be weak due to the large angle about the *along* axis. As the positive end of the range is approached, the diffraction will increase until it reaches a maximum at the right hand spot. The intensity then decreases as it nears the +38° *across* limit, at which point it diffracts to a point below the lower left hand edge of the pattern.

Due to its being symmetrical to $(31\bar{3})$ the (133) plane behaves in the same manner, except with its directions on the pattern reversed.

The $(\bar{1}33)$ plane at +38° *along* diffracts to the center of the arc, while at −38° *along* its diffraction is beyond the left hand end of the arc. Its diffraction reaches a maximum at the right hand side of the left hand spot.

The $(1\bar{3}3)$ plane will diffract very weakly, because its diffracting position requires that the crystal fragment be near the edge of the *along* range. Its diffraction will include the right hand half of this arc.

The $(13\bar{3})$ plane will likewise diffract very weakly and will include the right hand half of this arc.

$\{210\}$. This family includes 12 planes, 8 of which can diffract in both the *across* and *along* direction. The arcs produced on the *across* and the *along* patterns bear the same relation to each other as that of the two $\{331\}$ arcs and the *along* $\{210\}$ is continuous for exactly the same reason. To show that the orientation range selected accounts for the spots on this arc on the *across* film, the diffraction of each plane which can get into a diffracting position will be traced.

The (210) plane will diffract to the right hand limit of the right hand spot at the −38° end of its *across* range. At the +38° end of its *across* range it diffracts beyond the right hand end of the arc, so that this plane will account for the right hand segment of the arc to the right of the right hand spot.

The (021) plane at −38° *across*, diffracts beyond the left hand end of the arc and on the +38° end of the *across* range diffracts to the left hand edge of the right hand spot, thus accounting for the segment of the arc to the left of the right hand spot, and showing maximum diffraction at the position of the left hand spot.

The (012) plane at +38° *across*, diffracts to the right hand edge of the right hand spot while at −38° *across* it diffracts beyond the left end of the arc, with the maximum intensity of diffraction at the position of the left hand spot.

The $(0\bar{1}2)$ behaves in exactly the same way, except with the directions reversed, since it is a symmetrical plane to the (012).

The $(10\bar{2})$ plane at −38° *across* diffracts to the middle of the left hand spot, while on the other end of the range the diffraction goes off the right hand end of the arc. The diffraction from this plane will be fairly strong, because the cube is near the center of the preferred range, around the *along* direction.

The (102) plane at −38° *across* diffracts beyond the left hand of the arc, while at +38° *across* it diffracts just to the left of the right hand spot.

We have, then, accounted for the intensity and position of the spots and arcs of the diffraction patterns for both the *along* and the *across* patterns and have shown that this orientation can produce no other diffraction patterns other than those obtained. We can say that this one preferred orientation range explains the diffraction patterns from both nickel and copper and that the range of preferred positions in these two metals is independent of the number of passes through the rolls. The probability that the crystal fragment is in the preferred range of positions is, with our technique, dependent on the number of passes up to about eight. By the end of the eighth pass, the probability that the crystal fragment occupies the preferred range is extremely high. Further passes through the rolls result in but little increase in the preferment of orientation.

3. Silver. The work that was done on silver has already been published,[47] and will be discussed here only sufficiently to enable the data to be readily correlated with that on aluminum nickel and copper. The diffraction patterns of the samples of rolled silver listed in Table 2, made with the X-rays impinging along the direction of rolling, showed the presence of all the diffraction arcs which can be obtained from silver. Each of these was of uniform intensity over the whole length of the arc, and showed the same relative intensity as in the standard "powder method" diffraction pattern of silver, except that the arcs due to the $\{111\}$ family appear to be slightly fainter. This smooth "'continuous arc" type of diffraction pattern indicates a completely random orientation about the *along* axis. The decreased intensity of the $\{111\}$ arc is due to the limited orientation about the *across* axis. This limited orientation permits the $\{111\}$ planes to acquire the proper angle for diffraction to the *along* patterns only when the crystal fragment lies near the edges of the *across* range of the preferred positions. Fig. 10 shows an example of this type of diffraction pattern, obtained when unfiltered X-rays were diffracted in the direction of rolling on Sample 9.

The patterns made by the diffraction of X-rays across the direction of rolling gave diffraction rings showing spots of increased intensity superimposed on the continuous arcs. Fig. 11 shows such a diffraction pattern, thus indicating a decided preferment of orientation, although not a complete preferment.

The interpretation of the diffraction patterns made of rolled silver demonstrated the presence of two symmetrical ranges of preferred positions. One of these two preferred ranges may be visualized as follows: Consider for purposes of reference the unit face centered cubic cell in the crystal fragment, with its cube face parallel to the surface of the foil and one of its face diagonals parallel to the direction of rolling. Using the other face diagonal as an axis, rotate the cube until the first face diagonal is not less than 12° nor more than 40° to the direction of rolling. The direction of rotation is such as to lower the end of the face diagonal which points in the direction of the end of the foil entering the rolls first. Now allow the cube to be rotated at random about the first face diagonal as an axis. At any point in this random rotation of the unit cube, the crystal fragment will be within the limits of its preferred positions in silver provided only that the face diagonal of the unit cell makes an angle between the limits of +12° and +40° with the direction of rolling. The other symmetrical orientation may be similarly visualized, the only difference being that the limits of rotation of the first face diagonal are −10° and −42°, so that the direction of rotation is opposite. The differences in the angular limits are within experimental error.

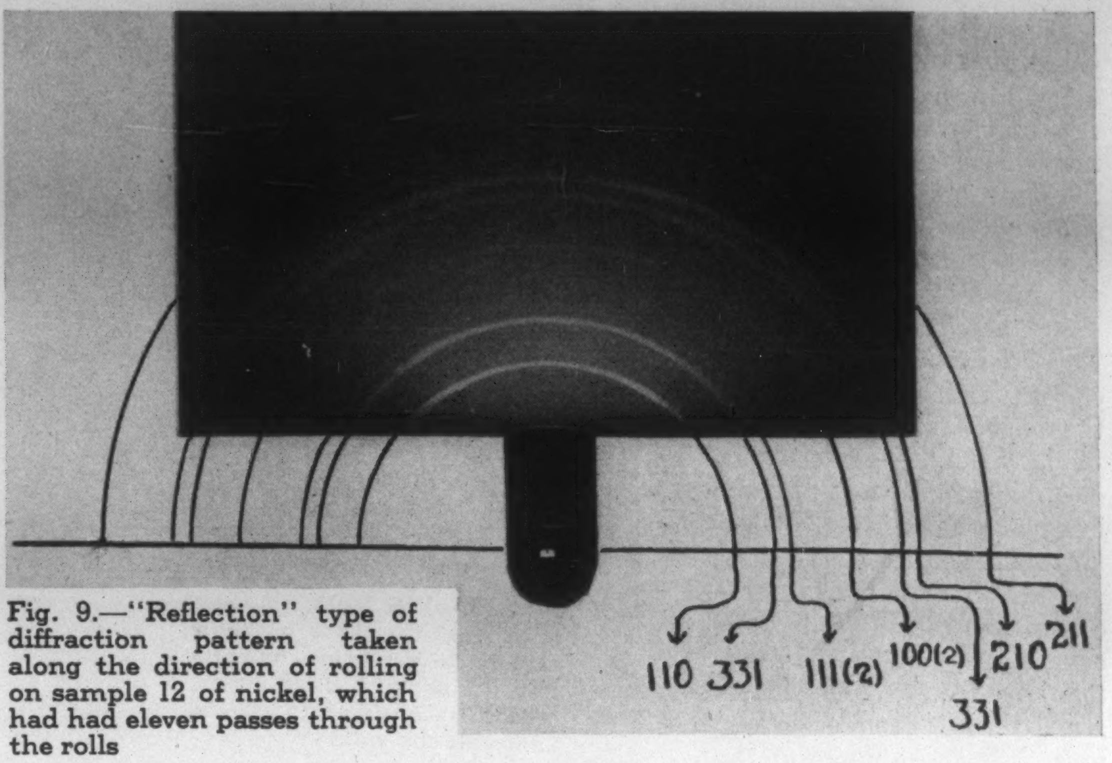


Fig. 9.—"Reflection" type of diffraction pattern taken along the direction of rolling on sample 12 of nickel, which had had eleven passes through the rolls

Expressed in the same convention set up for aluminum, nickel and copper these orientation ranges are ones with random orientation about the *along* axis and with limits between +12° and +40° *across* and between −10° and −42° *across*. (It will be noted that our convention of signs is opposite to that used in the original publication on silver.[47])

Separate interpretations were made of each of the diffraction patterns of each sample of silver listed in Table 2. The results of these interpretations are listed in Table 4, using the same convention of signs as in the preceding paragraph and as outlined in the beginning of Section IV, part b. It will be noted that these orientations show no definite effects of either percentage reduction per pass or absolute reduction per pass. With the exception of the first and possibly the second passes these orientation ranges are close enough to a mean to suggest that the variation between them may be due to slight differences in technique and to uncertainties in locating the ends of the spots on the diffraction pattern. The average of the mean of the positive ranges about the *across* axis, is within the precision of the data, the same as the average of the negative ranges about this axis. This shows that the fragments tend to assume two orientations which are symmetrical with respect to the surface of the sheets.

V. CORRELATION AND DISCUSSION OF THE DATA

a. Comparisons of Orientations Found in the Four Metals.

THE orientations found in the four face centered cubic metals, aluminum, nickel, copper and silver are similar in that for each of them one face diagonal of the cube always lies in a plane which is parallel to the direction of rolling and perpendicular to the rolling surface.

The behavior of nickel and copper is identical in every respect. Silver behaves in the same way that these two metals do, in that the number of passes through the rolls had no effects on the limits of the preferred ranges of positions. It is similar to them in that it shows a range of preferred positions symmetrical to the surface of the sheet. The preferred orientation in silver differs from that in nickel and copper in that, in silver there are two symmetrical preferred ranges about the *across* axis, with no limitations about the *along* axis, while in nickel and copper there is only one symmetrical preferred range of positions about the *across* axis, with symmetrical limits about the *along* axis as well.

The behavior of aluminum on cold rolling is different from that of the other three metals in almost every respect except the general similarity mentioned above. The limits of the preferred positions found in aluminum vary on rolling instead of remaining unchanged as in the others. Like silver, aluminum shows two ranges of positions about the *across* axis, but unlike silver these ranges are unsymmetrical. Aluminum is the only one of the four which shows variable limits around the *along* axis. The orientation about this axis is composed of two ranges in some samples and in others of only one and in every case the outer limits are unsymmetrical.

b. Comparison of These Results with Previous Work.

Several different preferred positions have been found in cold rolled face centered cubic metals by different workers. Each of these different results will be taken up in turn and compared with the results presented here.

The preferred orientation which has been confirmed by most of the experimental work in the literature and which has been reported for all of the face centered cubic metals is one in which a [112] direction is in the direction of rolling and a (110) plane parallel to the surface of the foil. Mark and Weissenberg[27,28] found this structure in silver, aluminum, gold, copper and platinum. Glocker and his co-workers[29,30,31,32] found it in silver, copper and aluminum. Tanaka [34] found it in aluminum, as did Norton and Warren.[38] Dehlinger[35] found it in aluminum, copper, silver, gold and platinum, while Eisenhut and Widmann[36] found it in copper.

Table 4.—Orientation Ranges Measured in Silver*
(Samples Listed in Table 2)

Sample No. See Table 2	Orientation Ranges Around the *Across* Axis (Angle between surface of sheet and line MN of Fig. 3)	Orientation Ranges Around the *Along* Axis (Angle between the original position of KL of Fig. 3 in the surface of the sheet and its limiting position when the crystal is rotated about MN as an axis)
2	From + 7° to +29° From −13° to −38°	Random
3	From +16° to +46° From −11° to −42°	Random
4	From +14° to +46° From −10° to −44°	Random
5	From +16° to +42° From −11° to −40°	Random
6	From +12° to −40° From −11° to −44°	Random
7	From + 8° to +44° From − 7° to −46°	Random
8	From +14° to +40° From −13° to −42°	Random
9	From +11° to +35° From −11° to −45°	Random
Average of Positive Ranges	From +12° to +40°	
Average of Negative Ranges	From −10° to −42°	

* For explanation of convention of signs, see text, Section IV, part b.

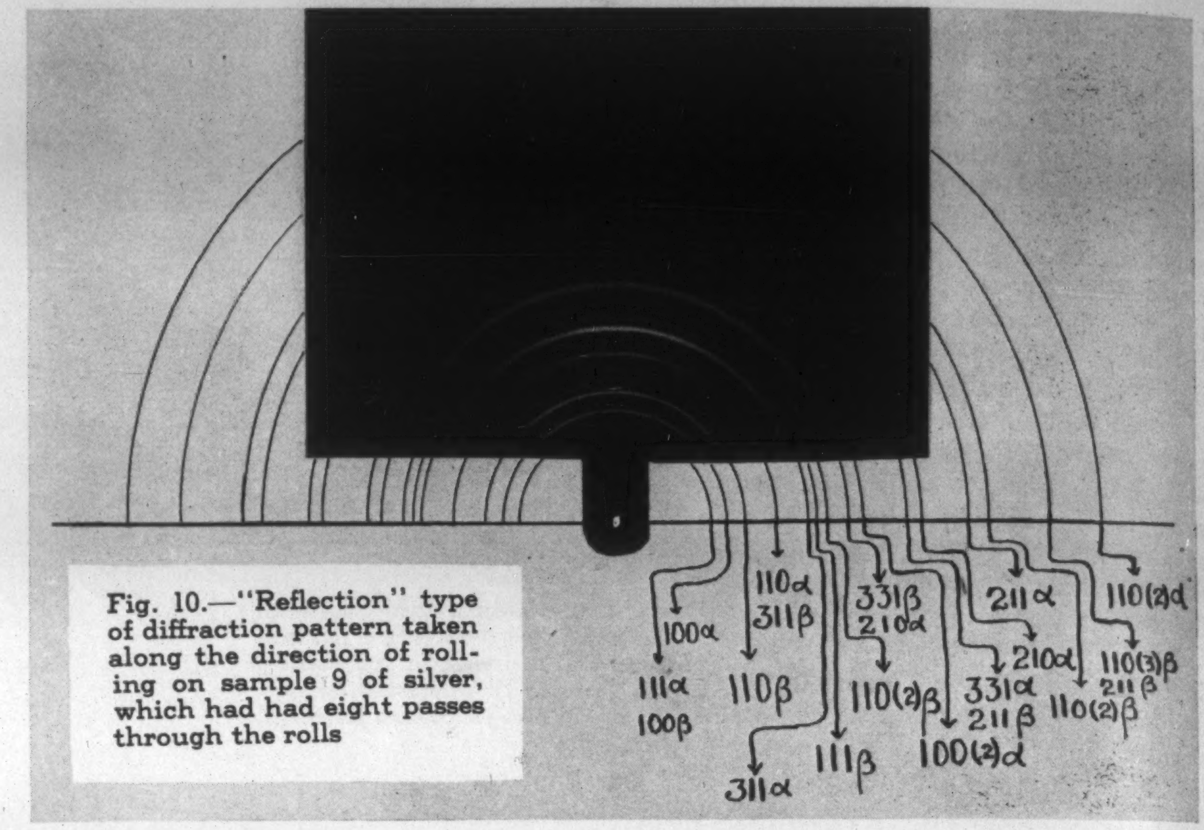


Fig. 10.—"Reflection" type of diffraction pattern taken along the direction of rolling on sample 9 of silver, which had had eight passes through the rolls

This orientation can be compared most readily with that found here by expressing it in the same terms. It is a position which is reached by giving the unit cube a rotation of either a +90° or −90° around the *across* axis, with an accompanying rotation of +30° or −30° about the *along* axis. This orientation has only one characteristic in common with the range of orientations which we have found—it keeps one face diagonal of the unit cube in a plane which is perpendicular to the surface of the sheet and which is parallel to the direction of rolling. It is, however, clearly outside the range for any of the four metals studied here, even when one uses the closest limits of the "scattering" of Mark and Weissenberg, namely, 35° on each side of an *across* angle of 90°. The largest angular rotations about the *across* axis found in our work was +45° in one sample of aluminum and +46° in two samples of silver. Our average was +40° for silver and +38° for nickel and copper.

The second preferred orientation found by Mark and Weissenberg, in silver, aluminum, copper, gold and platinum has a [100] direction parallel to the rolling direction with a scattering of 8° and a (100) plane parallel to the plane of rolling with a scattering of 40°. This orientation is outside our preferred range of orientation, since it has a cube edge in the direction of rolling instead of a face diagonal.

Konobejewski[37] reported a preferred position for nickel which is related to the first one discussed. In the position which he reports, the (110) plane is in the direction of rolling and the [211] direction makes an angle of 8° with the direction of rolling. In our terminology this is a position secured by a rotation of +90° *across* and −38° *along*. As in the case of the first orientation discussed above, it is a somewhat related structure, but outside our preferred range of positions.

Owen and Preston[33] found an orientation in rolled aluminum which, when expressed in our nomenclature, is one where there is a zero rotation about the *along* axis and a rotation of approximately 20° about the *across* axis. This position falls into the preferred ranges measured for aluminum except those for the last two of our samples which showed a break in the *along* range between ±4°.

Tanaka[34] found another preferred orientation of aluminum in addition to the one described. In this one the (001) planes are parallel to the surface of the foil and the [110] direction corresponds to the direction of rolling. In our nomenclature this is a position in which there is a 0° rotation about the *along* and the *across* axes. This position is not included in the ranges reported here, but is a related structure in that the face diagonal is in the direction of rolling.

The conclusions of Wever and Schmidt[4,5,39,40] to the effect that the textures of rolled aluminum, copper and silver are frequently not duplicated due to slight differences in rolling technique, are checked by the present work as far as aluminum is concerned and possibly for silver, but certainly not for copper and nickel. This work has shown that aluminum is much more sensitive to slight differences in rolling than any of the other metals studied. These authors claim that the structures found by Mark and Weissenberg represent a condition of incomplete rolling. The present work is not in agreement with this claim since even the metal foils with only one pass did not show the structures obtained by Mark and Weissenberg.

The probable reason for the difference between the results obtained here and those of previous workers lies in the fact that our determinations were made on relatively thick sheets of metal (0.320 to 0.050 cm.), whereas all the previous determinations were made on very thin foils. There is certainly reason to expect that a foil of a thickness which can be used for transmission patterns will show a different condition of orientation than one many times this thick. A very thin foil will have an oriented structure clear through its entire thickness because all of the metal has been severely cold worked, while with our thicker sheets of metal the inner layers are subjected to much less strain. This would mean that our sheets of metal have an orientation layer on each side of a less severely strained central layer. This central layer acts as a cushion so that the straining of each surface layer takes place from only one side. With the very thin foil the highly oriented surface layer extends clear through to the middle, there is no cushioning action and the metal is strained clear through from both sides. This should result in a different direction of metal flow under the rolls for our samples as compared with the samples of other workers. We believe that our results can be more directly translated into what happens in actual rolling practice.

c. Significance of Results Presented Here.

From the metallurgical standpoint the present results are of importance since they are the first determinations which have been made on preferred orientation in the surfaces of sheets of metal thick enough to be of practical use. All previous results have been obtained using foil of such thicknesses that can have only limited practical application. Preferred orientation on metal surfaces is important to the practical metallurgist because it is closely tied up with strain hardening and bids fair to have great value as an index to the properties of cold deformed metal. (See paper by Fuller and Edmonds on Preferred Orientations in Zinc Surfaces. Sept. 1931 meeting of the American Institute of Mining & Metallurgical Engineers.)

From the viewpoint of the physical chemist these results are of interest because they give experimental proof that the lattice forces in nickel and copper are very similar, while those of aluminum and silver are different. These differences are clearly not tied up with the crystal structure, for all four of these metals are face centered cubic. They are not tied up with atomic size, for silver and aluminum (which gave widely

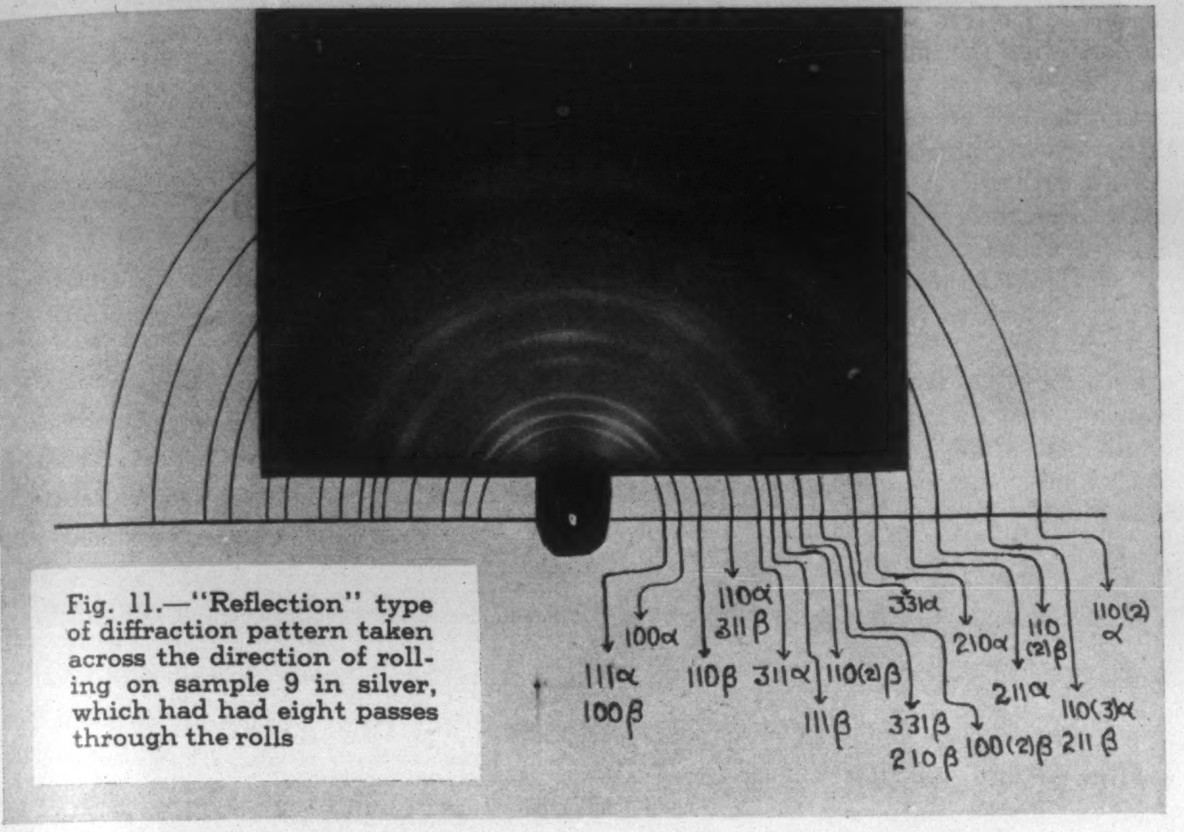


Fig. 11.—"Reflection" type of diffraction pattern taken across the direction of rolling on sample 9 in silver, which had had eight passes through the rolls

different results in our experiments) have lattice parameters which differ by only a fraction of a percent. These metals do, however, differ in valence. Silver has a valence of one, i. e., it is pictured as having a single valence electron. Copper shows chemically a valence of one or two, but prefers two; the bivalent copper forming the most numerous and stable compounds.* Apparently it may be pictured as having by preference, two valence electrons. Nickel shows chemically a valence of two, and may be pictured as having two valence electrons. Aluminum must be pictured as having three valence electrons. It is reasonable to suppose that this similarity in the number of valence electrons for nickel and copper should result in similar lattice forces and, therefore, should lead to identical orientations after rolling. It is inevitable that metals having one, two or three valence electrons should have differences in their lattice forces and it is reasonable to assume that these differences would affect the preferred orientation of the crystal fragments in the rolled sheets. It is this sort of difference which we believe we have found.

It will be interesting to make a few speculations as to what these preferred orientations may mean from the standpoint of the physical chemistry of the atom. It is not to be expected that the reader will take these speculations as necessarily representing reality; it may be too much to expect that he will take them as representing even approximate reality. It will be sufficient if he is introduced to the germ of a new point of view, somewhat different from that usually held, and if he finds in this point of view encouragement for undertaking some new line of research bearing on the orientation problem.

In order to insure clearness of presentation these speculations will be presented in terms of a definite picture of atomic structure which assumes that we can write down fixed coordinates not only for the mean positions of atomic centers, but also for the mean positions of the individual valence electrons. This does not limit the generality of such conclusions as may be drawn, for it has already been shown[48] that any conclusions as to the ordinary properties of materials, based on one type of atomic structure can be transferred bodily to any other.

The coördinates of the atoms in a face centered cubic lattice are:

M	N	P
$M + 1/2$	$N + 1/2$	P
$M + 1/2$	N	$P + 1/2$
M	$N + 1/$	$P + 1/2$

where M, N and P are any integers. They represent, respectively, lengths along the three axes of the cube, using the length of the cube edge as the unit of measure. These coördinates are the same for all face centered cubic materials, and therefore apply to the atoms of Ag, Ni, Cu and Al. Calculations by J. J. Thompson[49] on the basis of a modified Coulomb's Law of Electrostatics, show that the ordinary mechanical and electrical properties of face centered cubic metals can be accounted for if we assume that the "atoms" represented by the above coordinates are really positively charged ions and that the valence electrons occupy mean positions as follows:

Valence electrons of a univalent element (such as Ag):

$M + 1/$	$N + 1/4$	$P + 1/4$
$M + 3/4$	$N + 3/4$	$P + 1/4$
$M + 3/4$	$N + 1/4$	$P + 3/4$
$M + 1/4$	$N + 3/4$	$P + 3/4$

Valence electrons of bivalent elements (such as Ni or Cu):

$M + 1/4$	$N + 1/4$	$P + 1/4$
$M + 3/4$	$N + 3/4$	$P + 1/4$
$M + 3/4$	$N + 1/4$	$P + 3/4$
$M + 1/4$	$N + 3/4$	$P + 3/4$
$M + 3/4$	$N + 3/4$	$P + 3/4$
$M + 1/4$	$N + 1/4$	$P + 3/4$
$M + 1/4$	$N + 3/4$	$P + 1/4$
$M + 3/4$	$N + 1/4$	$P + 1/4$

Valence electrons of a trivalent element (such as Al):

$M + 1/4$	$N + 1/4$	$P + 1/4$
$M + 3/4$	$N + 3/4$	$P + 1/4$
$M + 3/4$	$N + 1/4$	$P + 3/4$
$M + 1/4$	$N + 3/4$	$P + 3/4$
$M + 3/4$	$N + 3/4$	$P + 3/4$
$M + 1/4$	$N + 1/4$	$P + 3/4$
$M + 1/4$	$N + 3/4$	$P + 1/4$
$M + 3/4$	$N + 1/4$	$P + 1/4$
$M + 1/2$	N	P
M	$N + 1/2$	P
M	N	$P + 1/2$
$M + 1/2$	$N + 1/2$	$P + 1/2$

The positions assigned to the valence electrons of a univalent element such as Ag represent a second face centered cube having axes parallel to the face centered cube of Ag^+ and having its origin of coördinates one-fourth the way along the body diagonal of the first. The symmetry of the structure as a whole bears marked points of resemblance to that of a face centered cube. If such a structure is taken to represent the actual structure of silver, it is to be predicted that silver would act toward mechanical forces much like the single face centered cube assumed in the literature.

In Ni or Cu, the valence electrons are placed by the coordinates on two face centered cubic lattices, both having their axes parallel to the face centered cube of Ni^{++} (or Cu^{++}). One of these electron lattices has its origin one-fourth the way along the body diagonal of the Ni^{++} (or Cu^{++}) cube, and the other has its origin three-fourths the way along. This second face centered cubic lattice of electrons introduces no new planes into the crystal which are not already present because of the first electron lattice. It is to be expected, therefore, that the preferred orientations of Ni and Cu will be identical, and will be closely related to those of Ag. Such differences as are found experimentally should be due to the additional interatomic forces introduced by the second electron lattice. These might be expected to result in narrowing the limits of preferred orientation. This is consistent with our experimental results which show that Ag has a random orientation about the *along* axis, while Ni and Cu show two symmetrically situated preferred orientations about the *along* axis.

---

* From the standpoint of physical chemistry this evidence is much more weighty than any theoretical calculations based on specific conductivity.

Thomson's coördinates for the valence electrons of Al^{+++} include not only the eight positions listed under Ni and Cu but also four additional positions. If we think of the Al^{+++} as taking the place of Na^{+} in NaCl, the third set of valence electrons would take the place of Cl^{-} in the NaCl. This introduces a new set of symmetry conditions which were not present in the case of Ag, Cu and Ni. Not only do we have additional directions for the interatomic forces, but the configurations of the electrons show new symmetries, which remind us somewhat of a body centered cube, superimposed on the face centered cube of Al^{+++}. These symmetries are sufficiently complex so that we might even expect Al to show preferred orientations which change with very slight changes in rolling technique.

If such a structure is seriously entertained, it is hardly to be expected that Al will act like Ag, Ni or Cu under mechanical working. Our knowledge of the mechanics of rolling is still in too uncertain a state to make it worth while to pursue our speculations further. It is sufficient for our present purpose to have described a picture of atomic structures which leads to the same results as our experimental data, namely that Ni or Cu show identical ranges of preferred orientations; that Ag shows a closely related preferred orientation; and that Al shows preferred orientations which are quite different from Ag, Ni and Cu, and which depend upon slight and unavoidable variations in even the most careful rolling technique.

Since these metals all have identical crystal structures, and since two of them have, within a fraction of one per cent, the same lattice dimensions, it is evident that the differences in preferred surface orientations which we have found can not be due to either crystal structure or atomic dimensions. We have shown that the differences found in preferred surface orientations may be accounted for in terms of the number of valence electrons of the atoms of these metals. We have stated in considerable detail one of the many possible pictures of atomic structure in order to enable the reader to visualize how the valence electrons of a metal may affect its mechanical properties, and we have pointed out that other, less arbitrary, atomic pictures must lead to the same result. We hope that, whether or not any of these pictures are adopted by the reader, the new viewpoint that valence electrons affect the properties of rolled metal will encourage others to work in this field.

VI. SUMMARY OF RESULTS

The preferred ranges of the crystal fragments in the surfaces of sheets of aluminum, nickel, copper and silver have been determined for a series of samples of each metal, with consecutively increasing number of passes through the rolls. The structures found in these metals were related, but not identical except in the case of nickel and copper which were identical in every respect. Aluminum was shown to be very sensitive to slight differences in rolling treatment. Nickel, copper and silver were shown to be comparatively insensitive, showing no differences with increasing number of passes through the rolls as far as limitation of the orientation ranges were concerned.

VII. ACKNOWLEDGMENTS

The writers wish to thank The Aluminum Company of America, Mr. W. H. Bassett of The American Brass Company and Mr. G. J. Hutzler of The International Nickel Company for their kindness in furnishing the samples on which the work was done. It is, too, a pleasure to express appreciation to the General Electric Company, Schenectady, New York for placing at our disposal facilities without which this research would have been exceedingly difficult, if not impossible.

VIII. REFERENCES

[1] G. Tammann. Lehrbuch der Metallographie. Verlag von L. Voss, Leipzig, 1914.

[2] E. C. Bain & Z. Jeffries. Mixed Orientation Developed in Crystals of Ductile Metals by Plastic Deformation. *Chemical & Metallurgical Engineering*, Vol. 25, 1921, pages 775–777.

[3] G. I. Taylor & C. F. Elam. Distortion of an Aluminium Crystal During a Tensile Test. *Proceedings Royal Society*, Vol. 102A, 1923, page 643.

[4] F. Wever & W. Schmidt. Texture of Cold Deformed Metals. *Zeitschrift für Metallkunde*, Vol. 22, 1930, pages 133–140.

[5] F. Wever & W. Schmidt. Texture of Cold Worked Metals. *Zeitschrift für technische Physik*, Vol. 10, 1929, pages 141–143.

[6] Davey, Nitchie & Fuller. Determining Orientation in Rolled Metal from X-ray Patterns Made by the Monochromatic Pinhole Method. *American Institute Mining & Metallurgical Engineers Technical Publication* No. 243E, 1929, page 88; *Transactions American Institute Mining & Metallurgical Engineers, Institute of Metals Division*, 1930, pages 557–564.

[7] A. W. Hull. The Crystal Structure of Aluminum and Silicon. *Physical Review*, Vol. 9, 1917, page 564.

[8] A. W. Hull. A New Method of Crystal Analysis. *Physical Review*, Vol. 10, 1917, page 661.

[9] P. Scherrer. The Crystal Structure of Aluminum. *Physikalische Zeitschrift*, Vol. 19, 1918, page 23.

[10] F. Kirchner. Experiments on Structure with X-rays. *Annalen der Physik*, Vol. 69, 1922, page 59.

[11] A. W. Hull. The Crystal Structure of Ferromagnetic Metals. *Physical Review*, Vol. 14, 1919, page 540.

[12] A. W. Hull. X-ray Crystal Analysis of Thirteen Common Metals. *Physical Review*, Vol. 17, 1921, page 571.

[13] F. Wever. Atomic Arrangement of Magnetic and Non-Magnetic Nickel. *Mitteilungen aus dem Kaiser Wilhelm Institut für Eisenforschung*, Vol. 3, 1921, pages 45–56.

[14] L. W. McKeehan. The Crystal Structure of the Iron-Nickel Alloys. *Physical Review*, Vol. 21, 1923, page 503.

[15] W. L. Bragg. The Crystal Structure of Copper. *Philosophical Magazine & Journal of Science*, Vol. 28, 1914, page 355.

[16] L. Vegard. The Structure of Silver Crystals. *Philosophical Magazine & Journal of Science*, Vol. 31, 1916, page 83.

[17] L. W. McKeehan. The Crystal Structure of Silver-Palladium and Silver-Gold Alloys. *Physical Review*, Vol. 19, 1922, page 537; Vol. 20, 1922, page 424.

[18] W. P. Davey. Precision Measurements on the Lattice Constants of Twelve Common Metals. *Physical Review*, Vol. 25, 1925, page 753.

[19] E. Hupka. *Physikalische Zeitschrift*, Vol. 14, 1914, page 623.

[20] N. Uspinsky & S. T. Konobejewski. *Lecture before the Russian Lebedew Society*, April 30, 1930, Moscow.

[21] K. Becker, R. O. Herzog, W. Jancke & M. Polanyi. *Zeitschrift für Physik*, Vol. 5, 1921, page 61.

[22] M. Ettisch, M. Polanyi & K. Weissenberg. The Fiber Structure of Metals—Wires of Copper and Tungsten. *Zeitschrift für Physik*, Vol. 7, 1924, pages 181–184.

[23] M. Ettisch, M. Polanyi & K. Weissenberg. X-ray Investigations on Metals. *Physikalische Zeitschrift*, Vol. 22, 1921, page 646.

[24] M. Ettisch, M. Polanyi & K. Weissenberg. The Fibrous Structure of Hard Drawn Metals. *Zeitschrift für physikalische Chemie*, Vol. 99, 1921, pages 332–337.

[25] M. Polanyi. The X-ray Fiber Diagram. *Zeitschrift für Physik*, Vol. 7, 1921, pages 149–180.

[26] M. Polanyi & K. Weissenberg. The X-ray Fiber Diagram. *Zeitschrift für Physik*, Vol. 9, 1922, pages 123–126; Vol. 10, 1922, pages 44–53.

[27] H. Mark & K. Weissenberg. Röntgenographic Determination of the Structure of Rolled Metal Foils. *Zeitschrift für Physik*, Vol. 14, 1923, pages 328–341.

[28] H. Mark & K. Weissenberg. Röntgenographic Determination of the Structure of Rolled Metal Foils. *Zeitschrift für Physik*, Vol. 16, 1928, pages 314–318.

[29] R. Glocker. Deformation and Recrystallization Structure of Metals. *Zeitschrift für Physik*, Vol. 31, 1925, page 386.

[30] R. Glocker & E. Kaupp. Observation on the Course of Recrystallization (of Silver) by Means of X-rays. *Zeitschrift für Metallkunde*, Vol. 16, 1924, pages 377–379.

[31] R. Glocker, E. Kaupp & H. Widmann. Recrystallization of Cold Rolled Silver. *Zeitschrift für Metallkunde*, Vol. 17, 1925, pages 353–357.

[32] R. Glocker & H. Widmann. Investigation of the Recrystallization of Silver, Copper and Aluminum. *Zeitschrift für Metallkunde*, Vol. 19, 1927, pages 41–43.

[33] E. A. Owen & C. O. Preston. The Effect of Rolling on the Crystal Structure of Aluminum. *Proceedings Physical Society*, London, Vol. 38, 1926, pages 132–147.

[34] S. Tanaka. The Effect of Rolling on Single Crystals of Aluminum. *Memoirs College Science Kyoto Imperial University*, Vol. 10, 1927, pages 303–309.

[35] U. Dehlinger. Recrystallization of Metals. *Metallwirtschaft*, Vol. 7, 1928, page 1172; *Annalen der Physik* (5), Vol. 2, 1929, pages 749–793.

[36] O. Eisenhut & H. Widmann. Studies on the Recrystallization of Rolled Copper Plates. *Zeitschrift für technische Physik*, Vol. 11, 1930, pages 70–76.

[37] S. T. Konobejewski. The Structure of Rolled Iron, Nickel and Molybdenum. *Zeitschrift für Physik*, Vol. 39, 1926, pages 415–426.

[38] J. T. Norton & B. E. Warren. Plastic Deformation of Metals. *American Institute Mining & Metallurgical Engineers*, No. 1610E, 1926, page 17; *Proceedings Institute of Metals Division, American Institute Mining & Metallurgical Engineers*, 1927, pages 350–366.

[39] F. Wever & W. Schmidt. Structure of Rolled Metals of the Face Centered Cubic Type. *Zeitschrift für technische Physik*, Vol. 8, 1927, pages 398–400.

[40] F. Wever. Texture of Metals after Cold Deformation. *American Institute Mining & Metallurgical Engineers*. Preprint, New York Meeting, Feb. 1931.

[41] W. P. Davey. A New Diffraction Apparatus. *Journal of the Optical Society of America*, Vol. 5, 1921, page 479; *General Electric Review*, Vol. 25, 1922, page 565.

[42] W. P. Davey. A Study of Crystal Structure and Its Applications. *General Electric Review*, Vol. 29, 1926, page 118.

[43] F. V. Göler & G. Sachs. The Recrystallization after Rolling Face Centered Cubic Metals. Parts I and II. *Zeitschrift für Physik*, Vol. 41, 1927, pages 873–888, 889–906.

[44] A. E. Van Arkel & M. G. Van Bruggen. Recrystallization Phenomena of Aluminum. *Zeitschrift für Physik*, Vol. 51, 1928, pages 520–523.

[45] R. J. Anderson. The Metallurgy of Aluminum and Its Alloys. Henry Carey Baird and Co., 1925.

[46] W. Duane. *Bulletin National Research Council*. I, No. 6, 1920.

[47] C. B. Hollabaugh. Preferred Orientation in Silver Foil Produced by Cold Rolling. *Metals & Alloys*, Vol. 1, 1930, pages 602–606.

[48] W. P. Davey. *Journal Franklin Institute*, Vol. 197, 1924, pages 439, 629.

[49] J. J. Thompson. The Electron in Chemistry. *Journal Franklin Institute*, Vol. 195, 1923, pages 593–620, 737–785; Vol. 196, 1923, pages 1–29, 125–180.

The Lead-Zinc Eutectic

(Continued from page 301)

Using a form of Van't Hoff's equation for freezing point lowering due to small additions of solute metal to a pure metal, the depression is found to be 1225° C. per gram mol of solute in 100 g. of solvent.[4] Since there are 65.37 g. of zinc per gram mol, and since the depression is $327.4 - 318.2 = 9.2°$ C:

$$\frac{9.2}{1225} \times 65.37 = \frac{.49\text{ g.}}{100\text{ g. solvent}}$$

or 0.49% Zn is required at the eutectic.

Analysis by microscopic and thermal methods shows a slight solubility of zinc in lead in the solid state. Thermal analysis shows 0.05% Zn in solution at the eutectic temperature.

The microscope indicates that zinc crystallizes as thin plates in the hypo-eutectic alloys.

Hyper-eutectic alloys are characterized by very large plates of primary zinc in a eutectic ground mass which is generally finer grained than the simple eutectic and which seems to have lost much of its zinc to the primary zinc plates. Slow cooled hyper-eutectic alloys are subject to drastic segregation of primary zinc due to gravity.

The eutectic composition as determined by thermal analysis and checked by microscopic analysis, hardness tests, and theoretical calculation, was found to be 0.50% Zn—99.50% Pb.

This investigation was undertaken at the suggestion of Dr. J. L. Bray, Professor of Metallurgy at Purdue University. The writers wish to acknowledge their indebtedness to Dr. Bray for his ready counsel and his material assistance in some of the analytical work.

[4] Schenck & Dean. Physical Chemistry of the Metals. John Wiley and Sons, 1919, page 45.

◆ ◆ ◆ ◆ ◆

Endurance of Welded and Unwelded Cast Wrought Materials[*]

BY W. B. BARTELS (Charlottenburg)

(A Critical Abstract by H. W. Gillett)

This extended study of the endurance of welded materials, with data on the properties of the unwelded materials for comparison, is of interest not only for the information on welds, but equally as a study of accelerated endurance test methods.

The endurance test specimen used, had a uniform diameter of 9.45 mm. (0.375 in.) over a 77 mm. (3 in.) test length. The shoulders were made with a 125 mm. (5 in.) radius. The test bar ends were tapered and held as in the R. R. Moore specimen.

The specimen was doubly loaded through ball races, as in the R. R. Moore machine, but instead of the load being applied by weights, it was applied, in the Schenck machine used, through lever arms and a jockey weight which could be run out on a graduated arm while the test was running. The specimen was run at 3500 r. p. m. in all tests.

Over the bearings through which the rotating specimen was loaded, were mounted two dials by which the deflection of the test specimen at any load could be measured to $^1/_{100}$ mm. By step-wise loading of the specimen (first run half an hour without load), with observations of the deflection after 15,000 cycles at a given load, stress-deflection curves could be plotted.

The power used by the motor at each step was also read by a precision milliammeter and a special voltmeter. Plots of power against stress could thus be drawn after the method advocated by Lehr.

An iron-constantan thermocouple was clamped tightly to the middle of the specimen by a split ring whose edges were rounded off. The thermocouple thus rotated with the specimen. The two elements were connected to collecting-rings, insulated from the specimen. Against these rotating rings were pressed brushes carrying the current of the couple to a millivoltmeter.

Thus three "accelerated" methods of endurance testing, the change-in-rate-of deflection, the power consumption, and the rise-of-temperature, could be used. The first two gave no great difficulty, but the last did, and was especially difficult on materials of high thermal conductivity such as aluminum alloys.

After the accelerated tests were finished, the probable endurance limit was estimated therefrom, and actual endurance tests run, first at a load 2 or 3 kg./mm.^{2} (2800 to 4300 lbs./in.^{2}) above the expected endurance limit, to produce fracture. Other specimens were then run at 1 kg./mm.^{2} (1400 lbs./in.^{2}) lower load, until a specimen remained unbroken for 10 million cycles.

When dealing with welded specimens, a second specimen was run to 10 million unbroken as a check. The 10 million figure was used for all materials, even the aluminum alloys, though such a short run is considered in America entirely inadequate to establish the endurance limit on aluminum.

Cast iron of 3.12% total C, 2.34% graphitic C, 2.65% Si, 1.05% Mn, 0.37% P, 0.027% S, 0.06% Cu, was poured in 25 × 1 in. diameter bars, and specimens taken from the center, which showed a tensile strength of 27,000 lbs./in.^{2}, 192 Brinell. The endurance limit was 10,700 lbs./in.^{2}. The rise-of-temperature figures could not be obtained. The power curve showed no hint of the endurance limit. The deflection curve was smooth (to the abstractor's eye), but by drawing tangents to the curve for 0–6 kg./mm.^{2}, and 8–16 kg./mm.^{2}, Bartels believes that a "rounded-off knee" can be shown which indicates the endurance limit.

In welding, the test specimen was machined down so that each abutting end was a 45° cone, the ends held in a special jig and gas welded with a suitable welding rod. After welding, the flame was reduced in size for slow cooling. The welded rod was machined down to the regular test bar size. Welding was done by experienced aircraft welders. The cast iron welding rod used was of 3.4% total C, 3.15% Si, 0.9% Mn, 0.7% P. The weld itself analyzed 3.21% total C, 2.18% graphitic C, 2.69% Si, 0.87% Mn, 0.56% P, 0.05% S, 0.12% Cu. One lot of welded specimens was tested without annealing, another after an anneal at 900° C. Both lots showed an endurance limit of 8500 lbs./in.^{2}. The deflection curve for the un-annealed specimen is drawn so as to show a knee at the endurance limit, but if the curve were drawn to the points instead of as a straight line, it would be hard to find the knee. There is no sign of a knee in the deflection curve for the annealed specimen and in neither lots do the power or temperature curves indicate the endurance limit, to the abstractor.

The next tests on cast iron were made on specimens cast as closely to the size of the endurance specimen as possible so as to clean up with the casting skin left on. The composition of the iron at the surface was 3.35% total C, 2.70% graphitic C, 2.58% Si, 0.99% Mn, 0.42% P, 0.03% S, 0.08% Cu. The center showed the same analysis within analytical error, but had 0.75% combined C instead of 0.65%. The endurance limit was very high, the endurance ratio being about 75%. The unwelded specimens tested without removing any more of the skin than was necessary to clean up the specimen, showed an endurance limit of 28,500 lbs./in.^{2} On welding (composition of welding rod and of weld not stated, but said to be close to that of the specimen), the endurance limit was 25,500 lbs./in.^{2}, welded and annealed in the welding flame, 22,800 lbs./in.^{2}, and welded and annealed in an electric furnace $^3/_4$ hour at 950–1000° C. and slow cooled, 21,500 lbs./in.^{2} On all these, the deflection curve gives no clear indication of the endurance limit, though in the unwelded specimen there is a slight discontinuity at the endurance limit, but the curve then resumes its former course. There are various irregularities in the power curve, taken to indicate the formation of slight cracks in the surface skin, but it would be impossible to predict the endurance limit from the power curves. The temperature curve only shows perceptible readings after the load is well past the endurance limit.

The fractures of the welded specimens were within the weld or at its ends. It is not clear why the welded specimens in this series of tests (skin on) should be so much stronger than in the previous series, since the fact that the bar itself has its casting skin cannot affect the weld.

---

[*] Die Dauerfestigkeit ungeschweisster und geschweisster Guss- und Walzwerkstoffe. *Giesserei Zeitung*, Vol. 27, Nov. 15, 1930, pages 607–616, Dec. 1, 1930, pages 637–645. Dec. 15, 1930, pages 661–669. 36 references.

In a series of tests on "pure" silumin and "cupro" silumin, materials of the following composition were used:

	Si, %	Cu, %	Fe, %	Al
Pure Silumin	10.25	0.50	0.24	Bal.
Welding rod for P.S.	10.14	0.46	0.70	"
Cupro Silumin	10.49	1.45	0.62	"
Welding rod for C.S.	9.80	1.03	0.77	"

The method of plotting the deflection curve used by Bartels for these tests draws a straight line from zero load to 4 kg./mm.^{2}, and another from 8 or 10 to 12 kg./mm.^{2} Where these intersect is assumed to be the endurance limit. In general, the 2 kg./mm.^{2} point is off the line, and that for 6 (and often for 8) kg./mm.^{2} is very far off. The abstractor can see no justification whatever for believing that the deflection curves tell anything about the endurance limit. Ordinarily no temperature curves were obtainable at all. In some cases, the power curve shows no increase in power required over that taken by the unloaded specimen until stresses are reached that are higher than that taken as the endurance limit.

Bartels manages to assume an endurance limit on the basis of his interpretation for the deflection or power curves, but does not come out very well in his comparison with actual endurance tests. On unwelded pure silumin, he takes 7800 lbs./in.^{2} as the endurance limit, and ran one bar at 8500, but it broke in 92,000 cycles. No tests are given at lower stresses. On pure silumin welded, he admits that two specimens tested by the accelerated methods did not check. He interprets one as showing 10,000, the other as 11,400 lbs./in.^{2} Only one set of values is plotted, and actual endurance tests broke early from flaws.

Another test was made on specimens with two welds instead of one. Even Bartels couldn't make the deflection curve indicate anything on this, but the power curve shows a real knee at 12,100 lbs./in.^{2} Specimens run at this load withstood 10 million cycles. The stress was then raised to 15,000 lbs./in.^{2}, and each of two specimens lasted about 12 million cycles, at this increased stress, before fracture.

Cupro silumin unwelded, broke after 11$^1/_2$ million cycles at 10,000 lbs./in.^{2} The deflection curve is interpreted by Bartels to show an endurance limit at 9300 lbs./in.^{2} This material welded with pure silumin is alleged to show an endurance limit of 11,400 lbs./in.^{2}, but a specimen actually run at this stress, broke after 261,000 cycles. Three welded specimens, annealed in the welding flame, broke in the lathe on machining down the weld.

The abstractor cannot accept either the "accelerated" or the regular endurance tests, run to so few cycles, as giving any real information on the endurance properties of these aluminum alloys.

Soft steels were tested as follows:

	C	Si	Mn	P	S	Cu
A	0.07	0.01	0.56	0.10	0.06	0.02
B	0.04	0.02	0.52	0.05	0.04	0.08
Welding rod for both	0.04	0.02	0.51	0.06	0.04	0.10

Endurance limits were, A, 40,000 lbs./in.^{2}, B, 36,500 lbs./in.^{2} In the accelerated tests, the deflection curve shows a weak knee around the endurance limit, the power curve does not show a break till a higher stress is reached. With A, the temperature curve might be taken as showing a fairly concordant figure, but not with B. Steel A welded, shows 34,000 lbs./in.^{2} endurance limit, while B shows 31,500 lbs./in.^{2}

The welded and annealed (10 min. in the welding flame) steel A had 33,500 lbs./in.^{2} endurance limit. On this, the power curve was so smooth that no guess as to an endurance limit could be made from it, while in the welded and unannealed, it turned up very sharply, though only at a stress above the endurance limit. In both, the deflection curves show a weak knee at the endurance limit, but the temperature curves are of no value in finding it.

Commercial aluminum (99.4, with 0.2% Cu) gave a life of 10 million cycles at 8500 lbs./in.^{2}, and on highly polished specimens, 10,000 lbs./in.^{2} The power curve shows a clear break, but this comes at 14,200 lbs./in.^{2} The deflection curve is drawn to agree with the 10 million cycle endurance limit only by entirely disregarding the point at 8500 lbs./in.^{2}

When welded with 98.6% Al containing 0.7% Cu, the welds had very low strength. After welding and hammering, the welds stood 10 million cycles at 8500 lbs./in.^{2}

Copper of 99.62% purity, welded with 99.97%, was studied. The temperature and power curves on unwelded specimens allowed no estimate of the endurance limit. The deflection curve showed a knee at 12,000 lbs./in.^{2} A regular endurance test bar was stopped unbroken at that stress after 12 million cycles.

Welded and hammered, and welded, hammered and annealed copper gave endurance limits (on the basis of 12 million cycles unbroken) of about 5500 and 6500 lbs./in.^{2}, respectively. The temperature and power curves again showed no consistent relation to the long-time test. The deflection curves as plotted show knees around the endurance limits indicated by the long-time tests, but if the observed points were followed in drawing the curves instead of drawing two straight lines, the exact location of the knee would be none too plain.

With a knowledge of the actual endurance limit, it is possible to look at any set of curves taken by the various accelerated methods, and figure out that some one of them might be interpreted as indicating the endurance limit. But if one decides on a general method of locating the endurance limit from the short time curves, and applies this without knowing the answer, decidedly poor results will be obtained. It is especially interesting to note that the power curves taken after the Lehr method are of so little value. That the rise of temperature method is useless, is now generally realized. The deflection method is usually also dismissed as useless, while the Lehr method is normally considered more promising. But Bartels' data shows the Lehr method to be even less promising than the deflection method.

Micrographs are shown of the structure of many of the various specimens tested.

Repeated impact tests were made on 10, 15 or 30 mm. diameter specimens, having the diameter reduced by 2 mm. by a round notch. Instead of turning the specimen 180° between blows, 25 blows were applied during each revolution of the specimen. The weight of the tup was 2, 3 or 4 kg. The height of fall and the number of blows per minute are not stated. Curves are given for results with various tups. The results of tests with the 2 kg. tup on the 10 mm. diameter bar, follow:

Material	Prop. Limit 0.001% Extension, lbs./in.^{2}	Yield Point 0.02% Extension, lbs./in.^{2}	Tensile Strength, lbs./in.^{2}	Elongation, %	Brinell	Endurance Limit, lbs./in.^{2}*	Repeated Impact, No. of blows
Cast iron, without skin, unwelded	8,600	....	27,000	..	192	11,500	54,253
Ditto, welded	8,300	....	10,000	..	192	8,500	2,305,538
Ditto, welded and annealed	....	....	....	..	...	8,500	218,532
Cast iron, with skin, unwelded	14,000	....	38,500	..	212	28,500	92,148
Ditto, welded	13,700	....	33,500	..	212	25,500	3,000,000[1]
Ditto, welded and annealed	....	....	....	..	...	21,500	73,210
Silumin, unwelded	4,500	9,500	19,500	..	59[2]	8,000	7,502
Ditto, welded	2,800	5,800	6,500[3]	..	58[2]	10,500[3]	10,542
Ditto, welded and annealed	....	....	....	..	...	5,000	9,650
Cupro Silumin, unwelded	5,500	10,500	16,500	..	58$^1/_2$[2]	9,500	13,377
Ditto, welded	4,000	7,000	10,500[3]	..	58[2]	11,500[3]	8,504
Ditto, welded and annealed	....	....	....	..	...	....	9,413
Soft Steel A, unwelded	30,000	37,000	65,500	25	143	40,000	13,000,000[1]
Ditto, welded	21,500	28,500	50,500	7	143	34,000	1,748,422
Ditto, welded and annealed	....	....	....	..	...	33,500	854,216
Aluminum, unwelded	12,500	15,000	17,500	9$^1/_2$	27[2]	8,500[1]	14,187
Ditto, welded	5,500	8,500	13,500	9	27[2]	8,500[1]	980
Ditto, welded and annealed	....	....	....	..	...	....	612
Copper, unwelded	22,500	35,500	39,000	9$^1/_2$	68[2]	12,000	164,602
Ditto, welded	9,000	11,000	17,500	7$^1/_2$	68[2]	5,500	16,111
Ditto, welded and annealed	....	....	....	..	...	6,500	18,272

* Note that the endurance limits of the non-ferrous metals and alloys are on the basis of only about 10 million cycles.

[1] Unbroken.

[2] 10 mm. ball, 1000 kg. pressure.

[3] Discrepancy—tensile strength of welded specimens below endurance limit.